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(54) **ROBOTIC NAVIGATIONAL SYSTEM FOR INTERBODY IMPLANTS**

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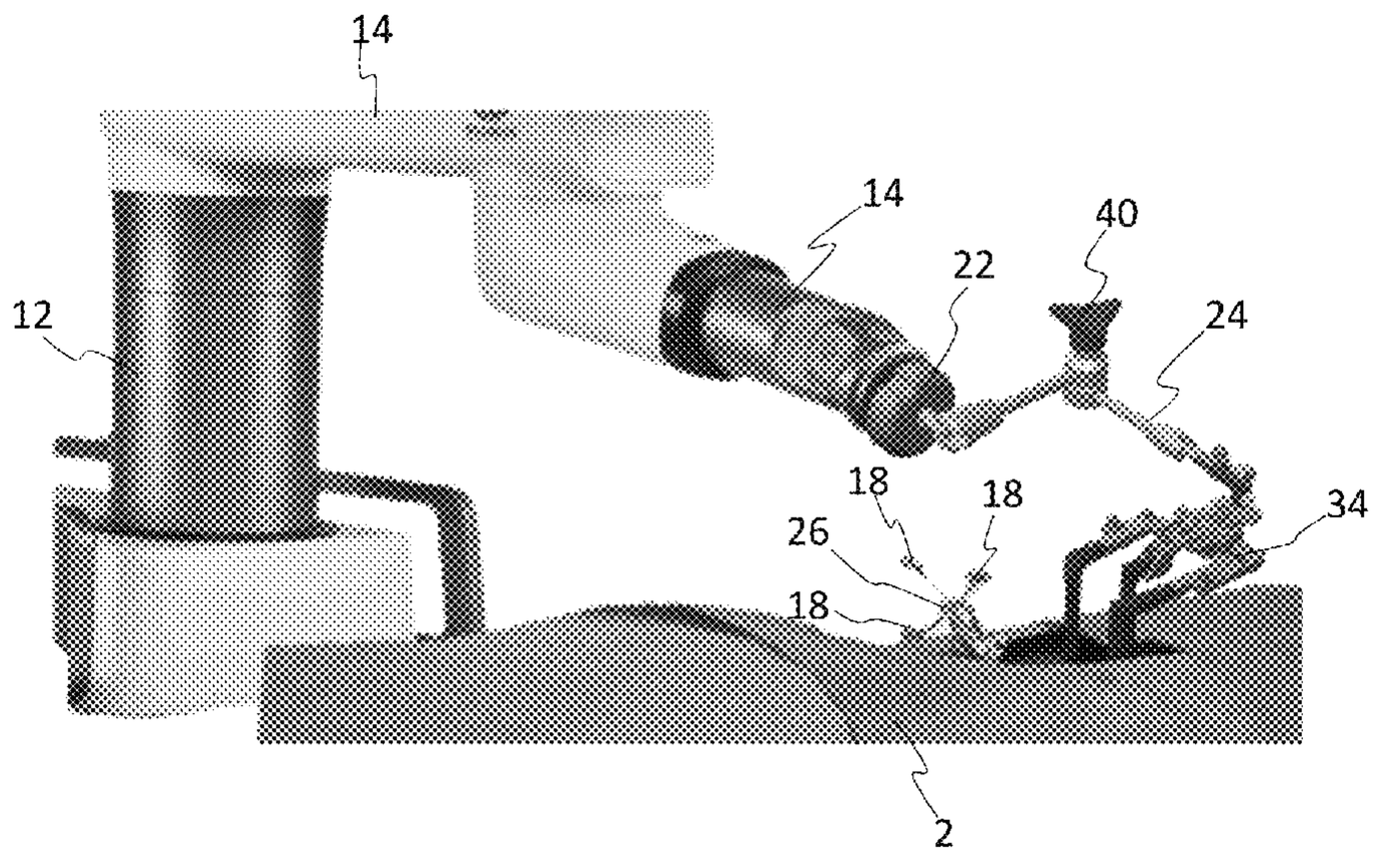
(57) **ABSTRACT**

Devices, systems, and methods for a robot-assisted surgery. Navigable instrumentation, which are capable of being navigated by a surgeon using the surgical robot system, and navigation software allow for the navigated placement of interbody fusion devices or other surgical devices. The interbody implant navigation may involve navigation of access instruments (e.g., dilators, retractors, ports), disc preparation instruments, trials, and inserters.

17 Claims, 42 Drawing Sheets



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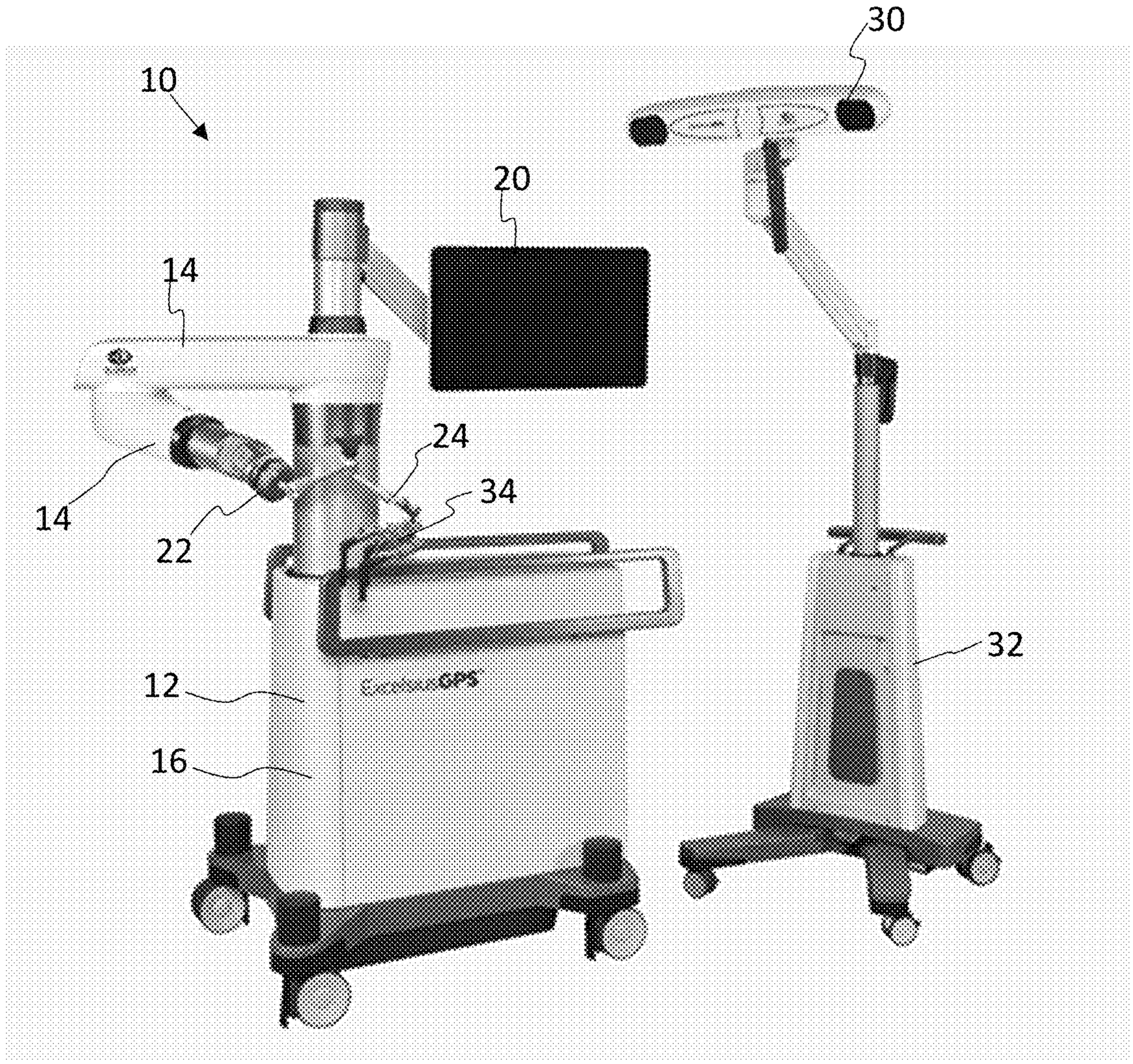


FIG. 1

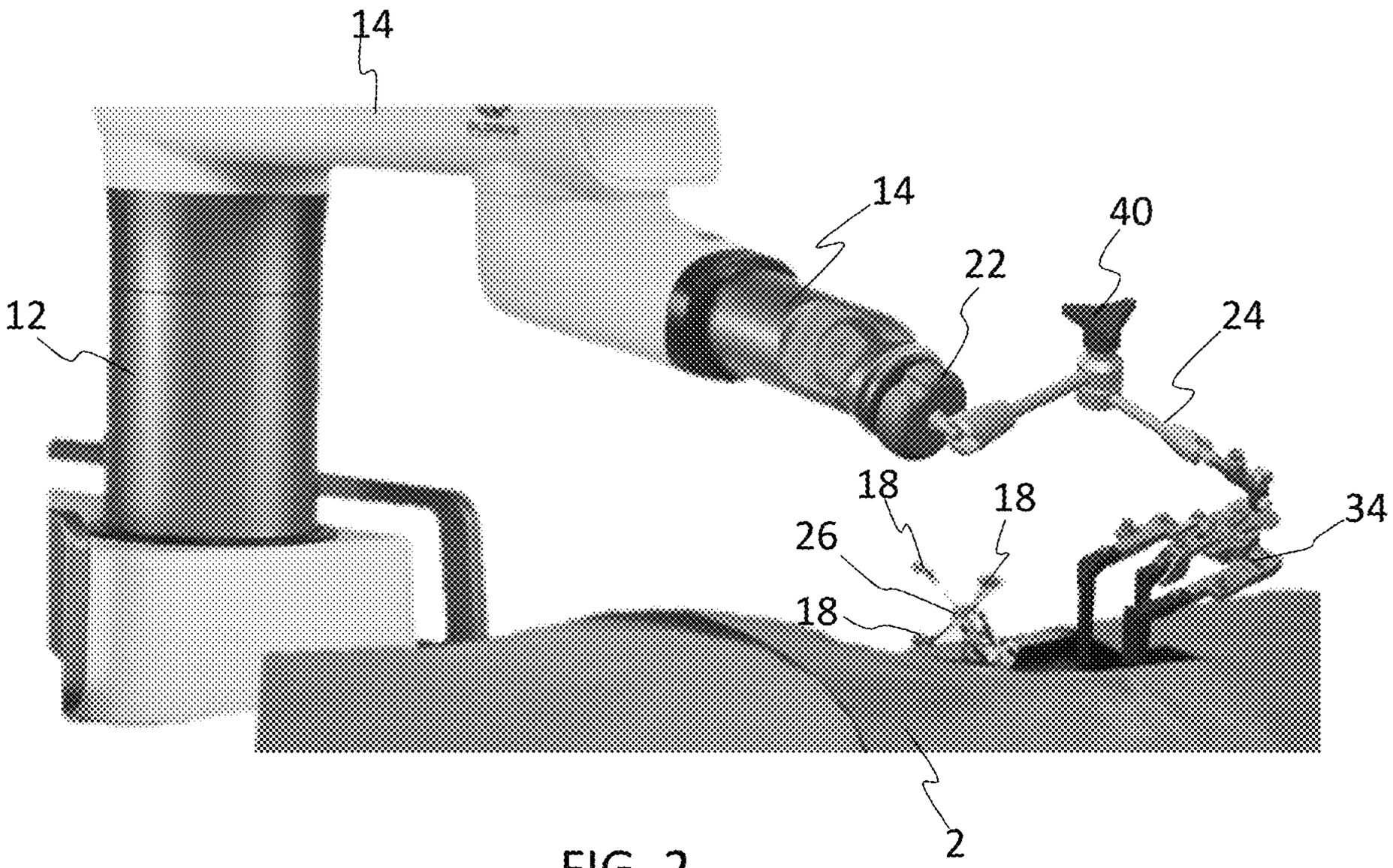


FIG. 2

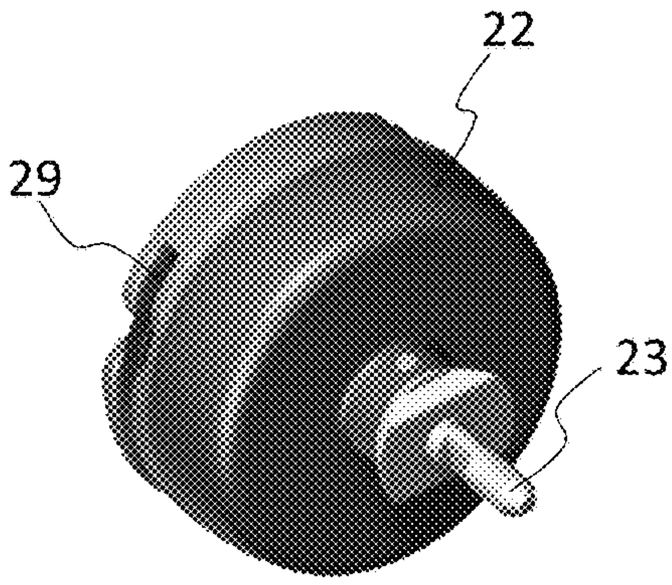


FIG. 3

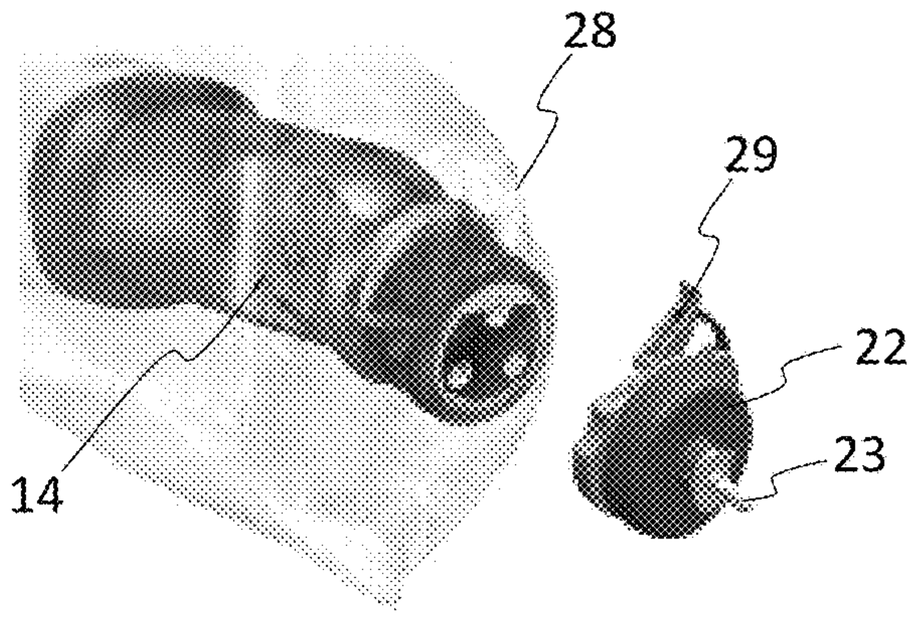


FIG. 4A

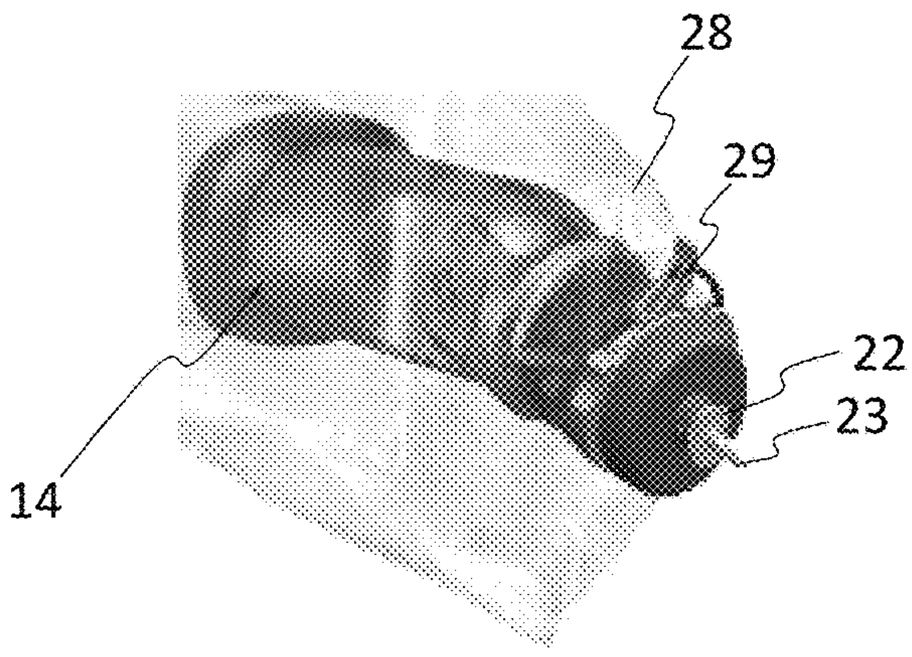


FIG. 4B

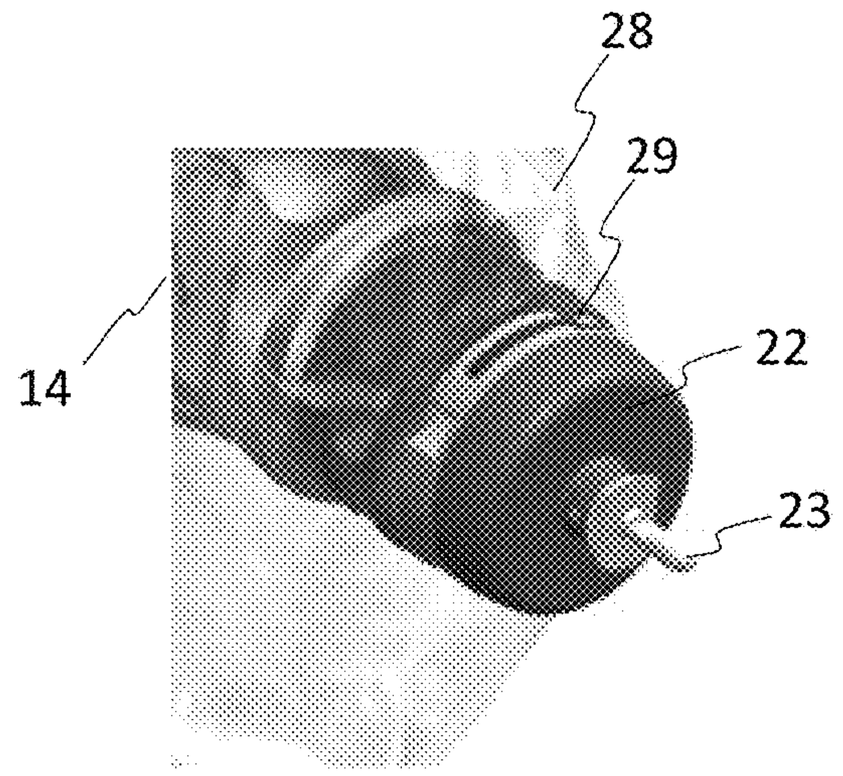


FIG. 4C

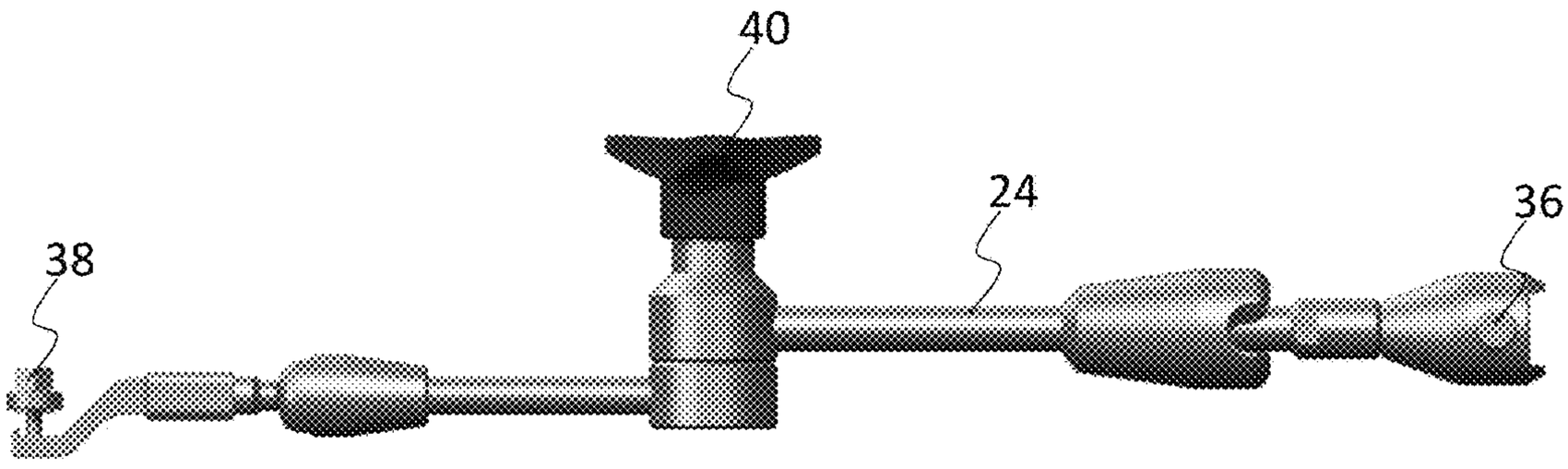


FIG. 5

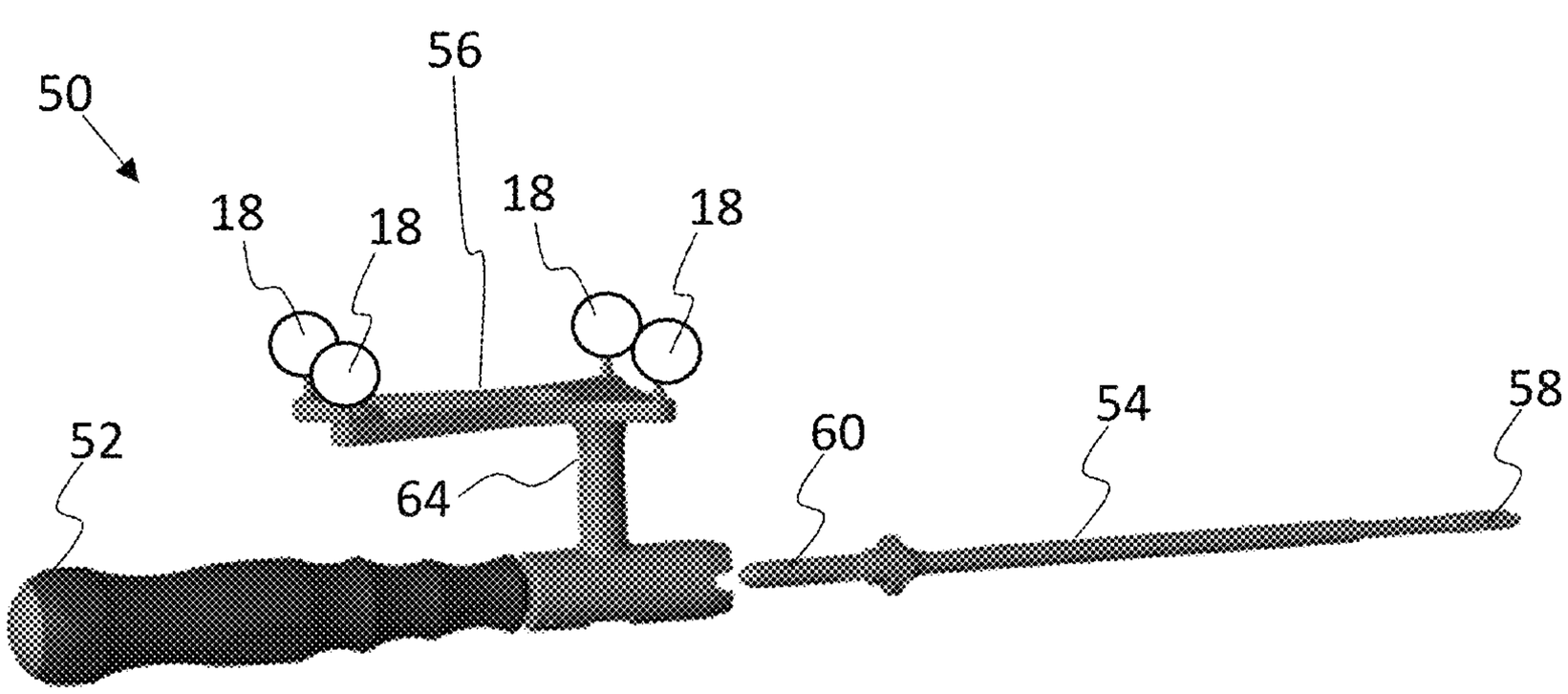


FIG. 6A

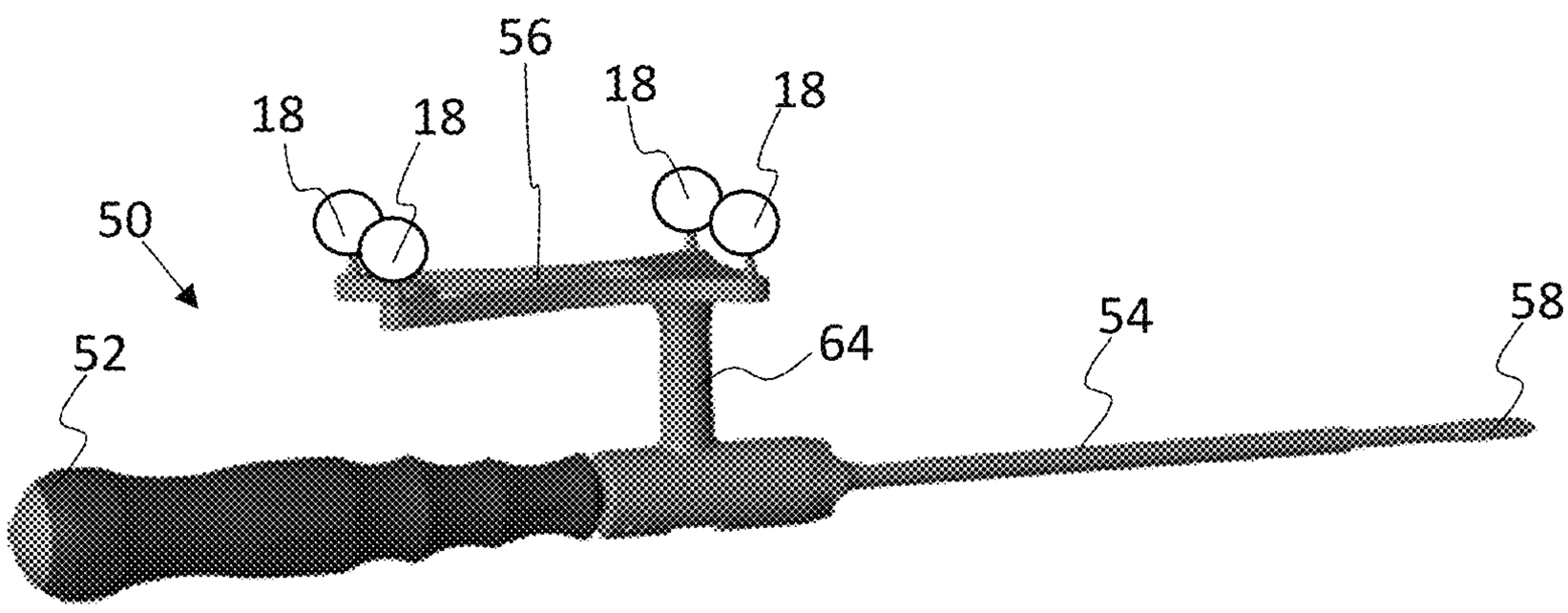


FIG. 6B

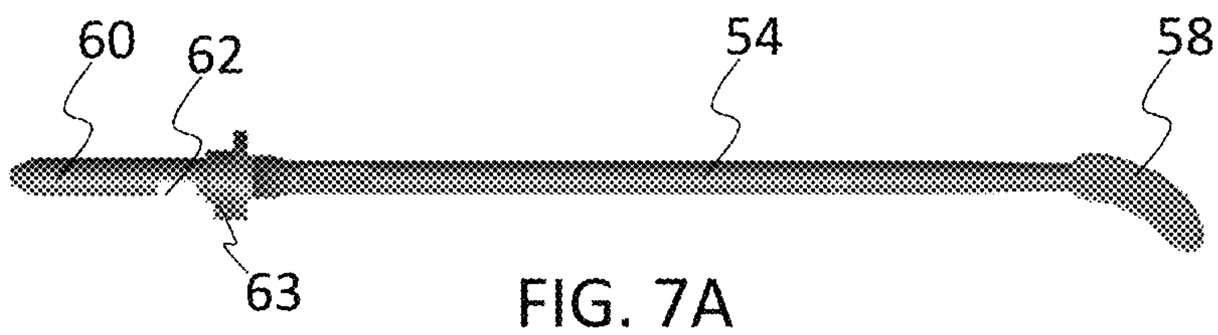


FIG. 7A

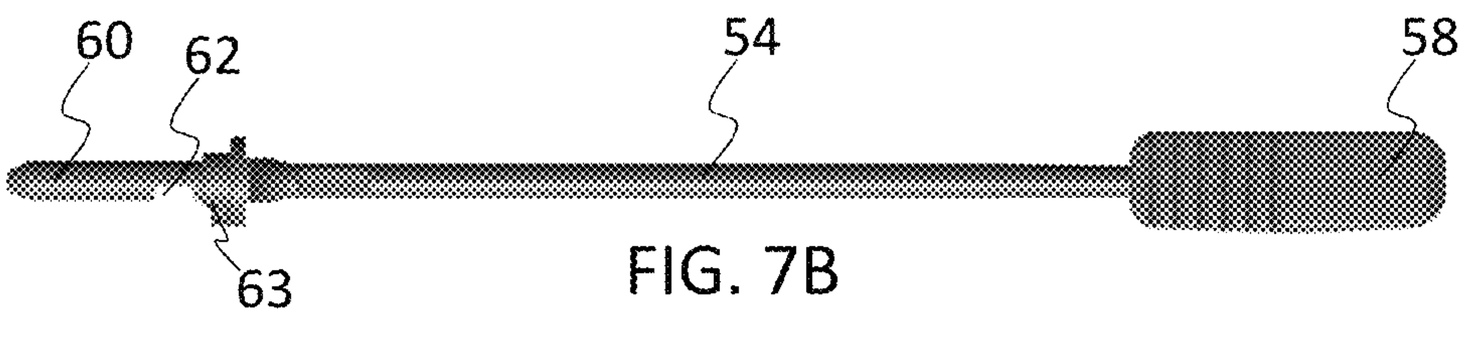


FIG. 7B

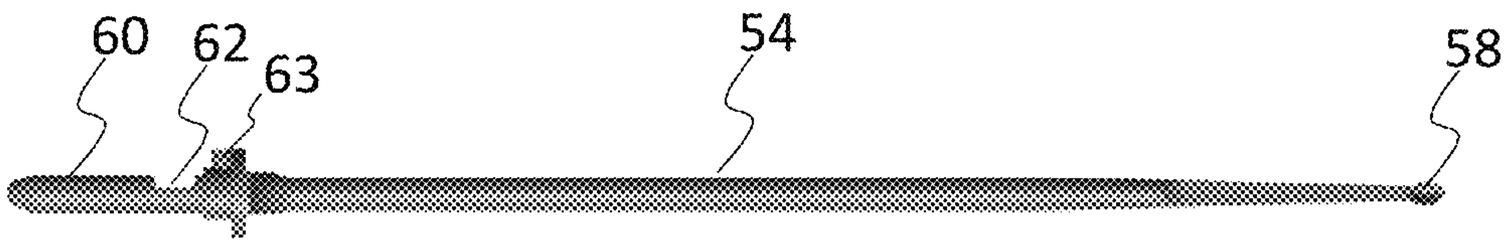


FIG. 7C

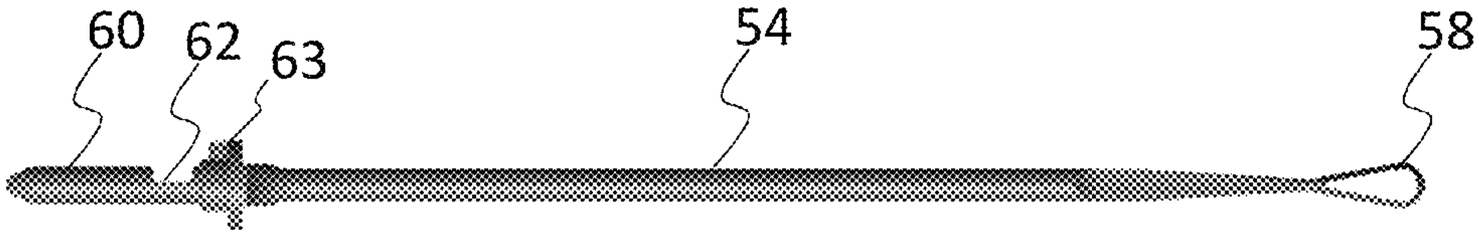


FIG. 7D

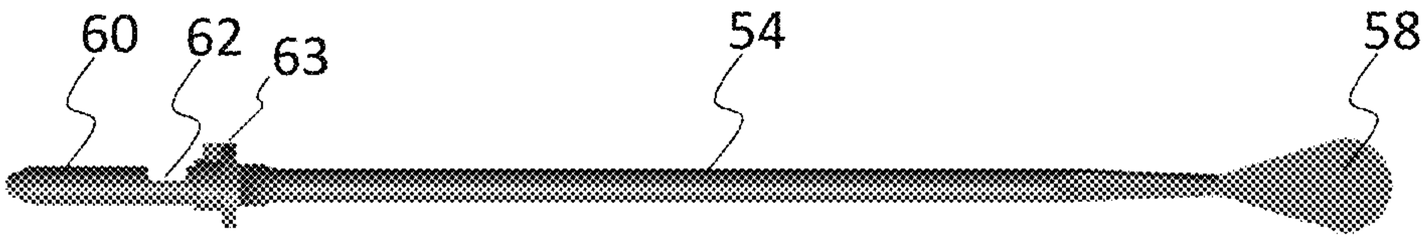


FIG. 7E

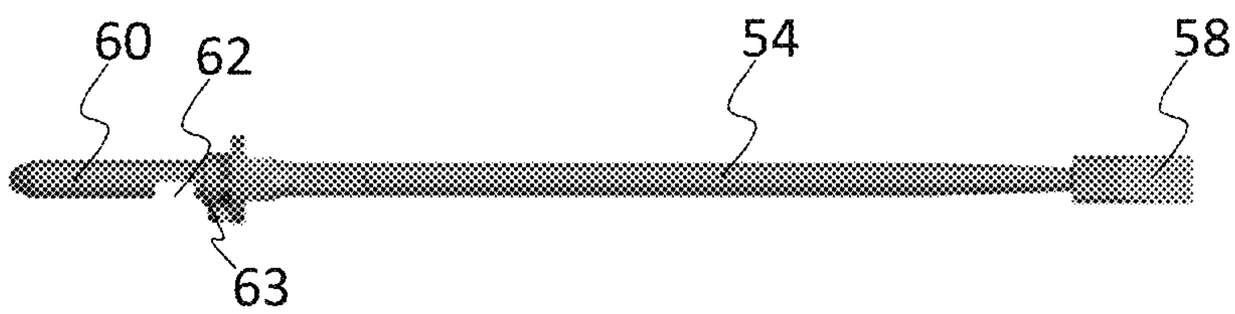


FIG. 7F

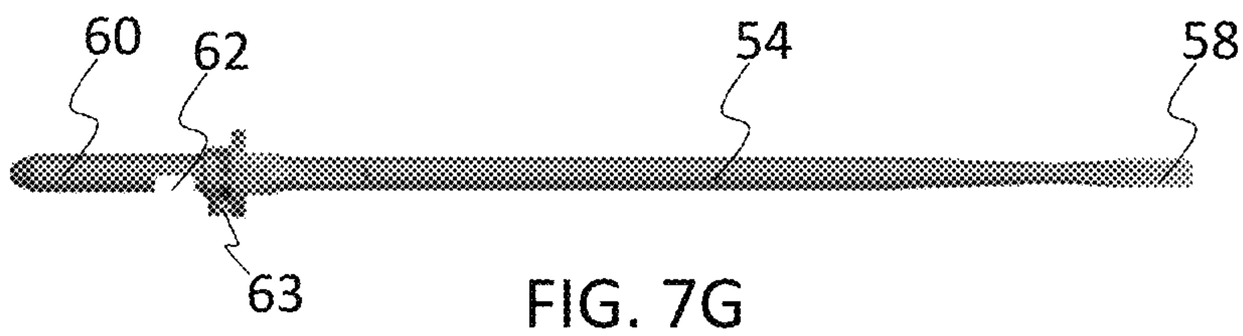


FIG. 7G

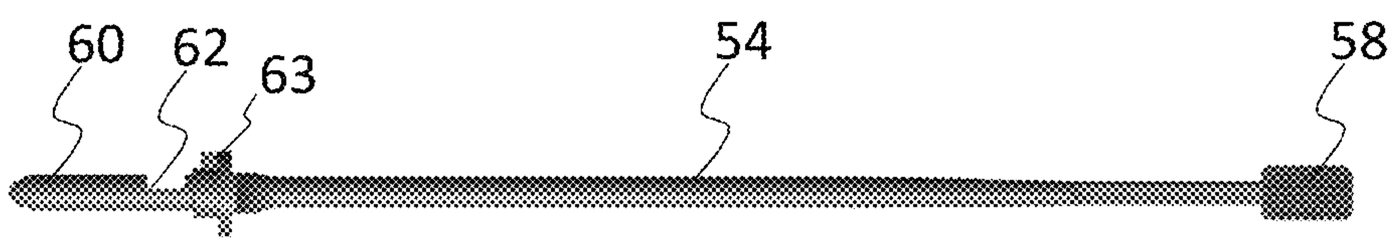


FIG. 7H

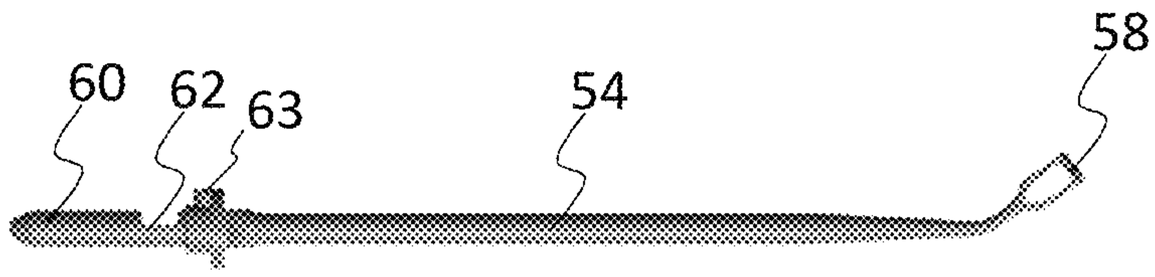


FIG. 7I

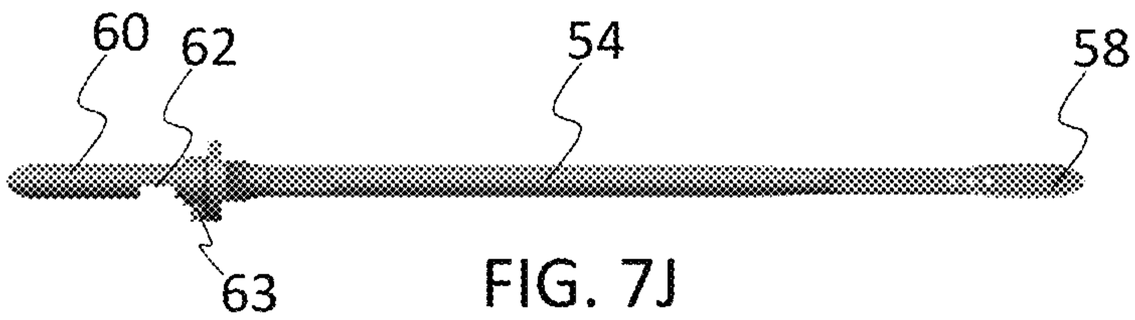


FIG. 7J

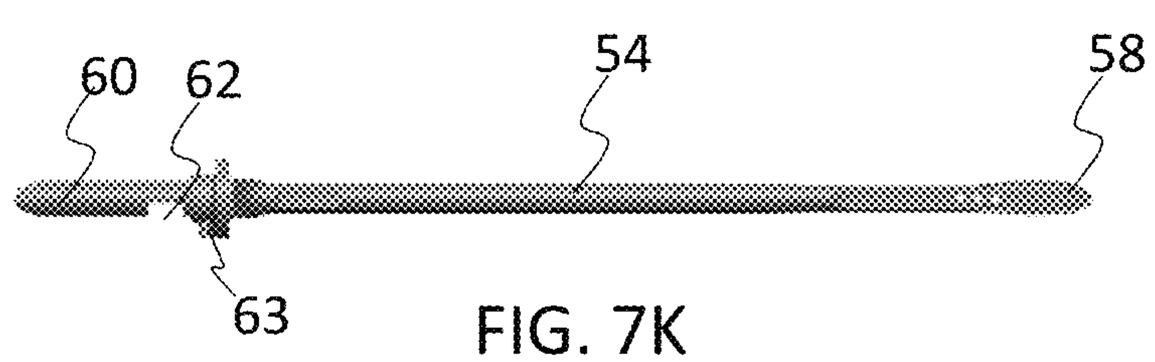


FIG. 7K

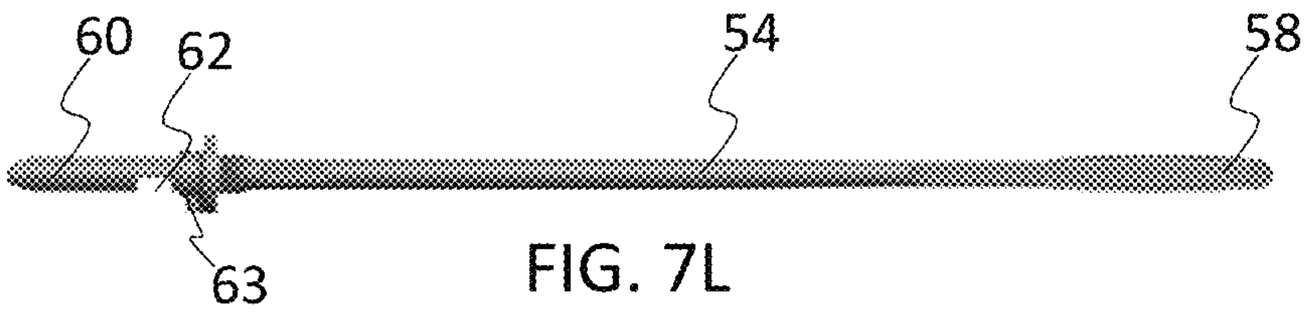


FIG. 7L

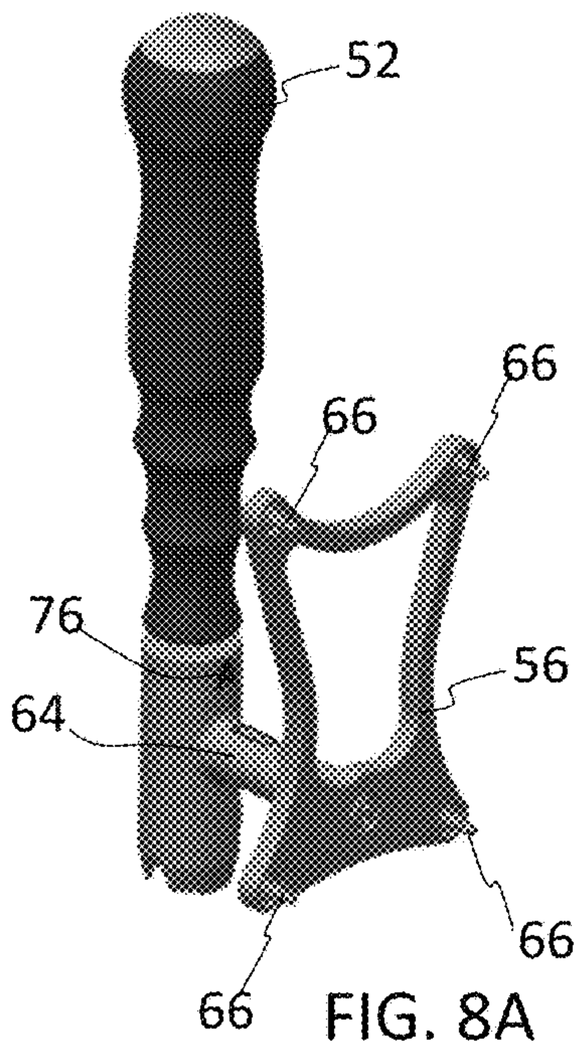


FIG. 8A

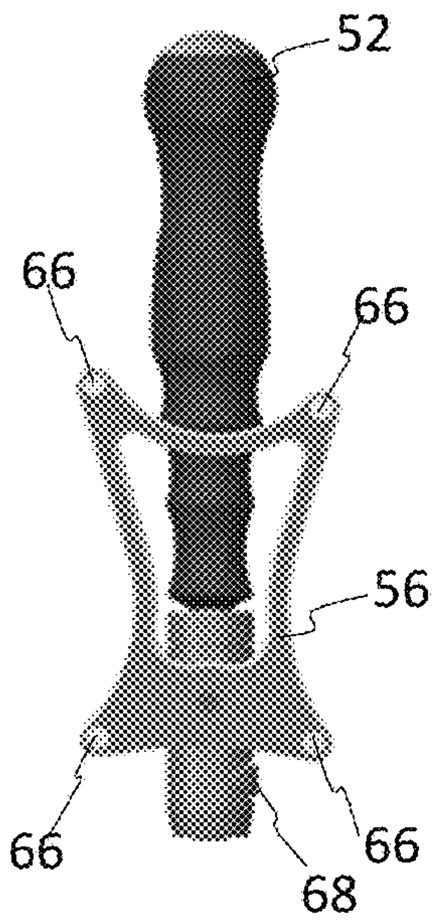


FIG. 8B

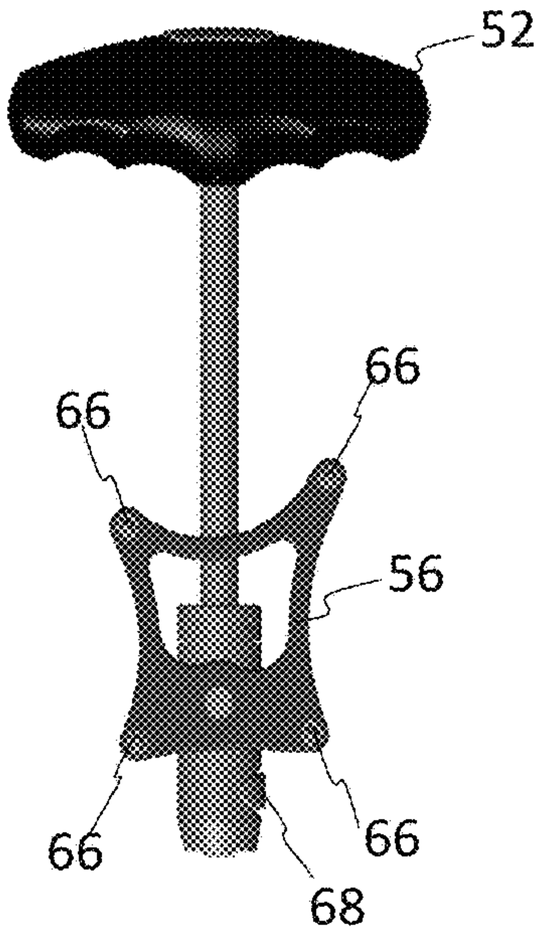


FIG. 8C

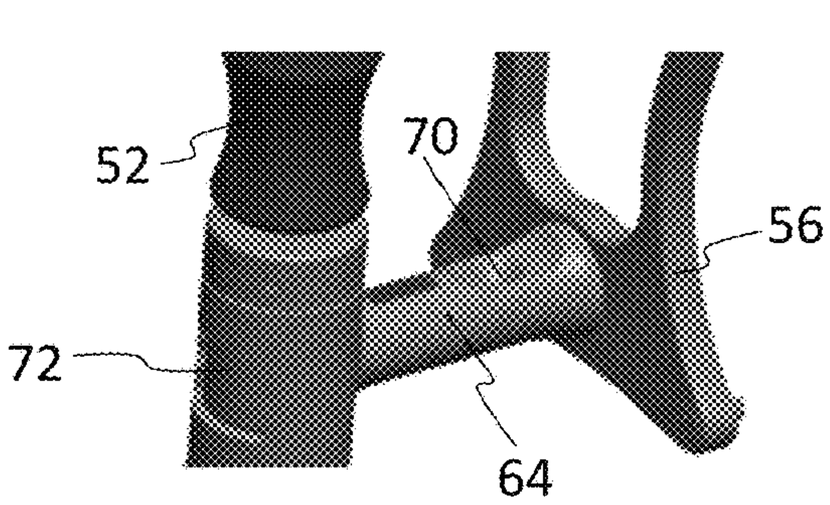


FIG. 8D

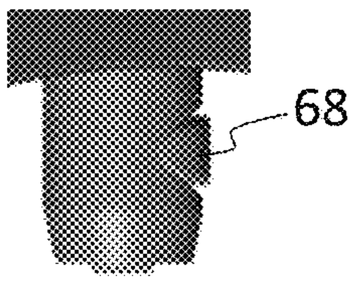


FIG. 8E

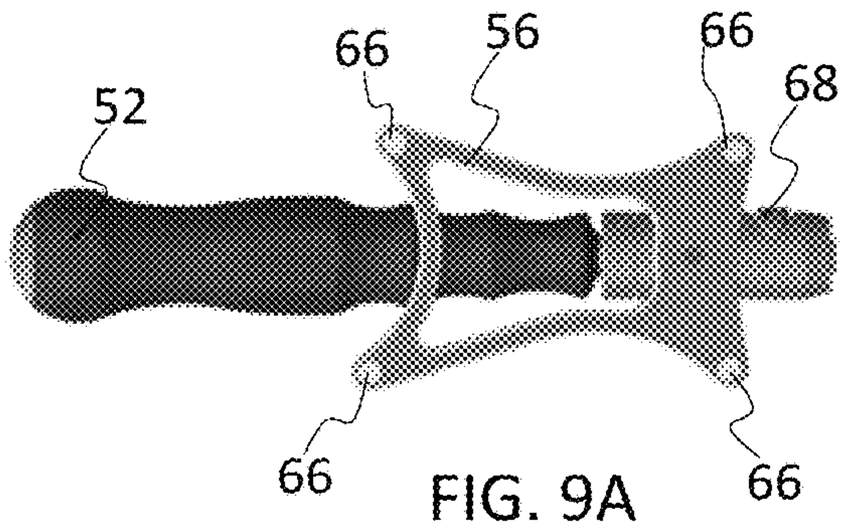


FIG. 9A

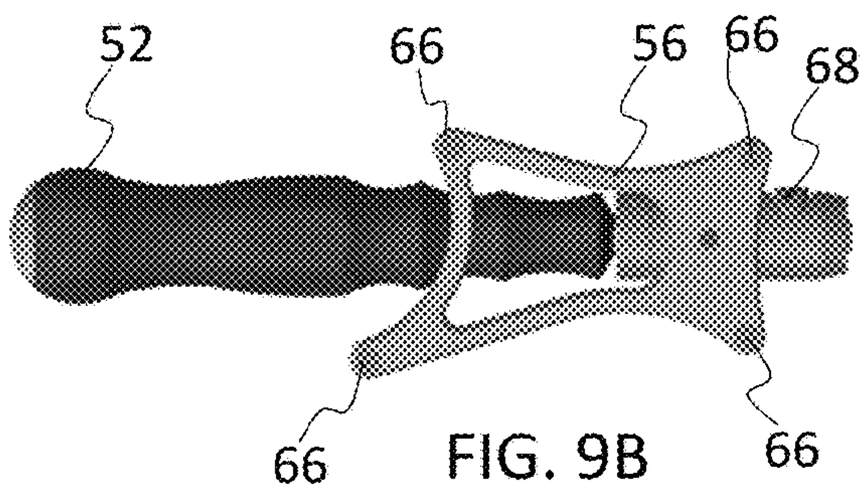


FIG. 9B

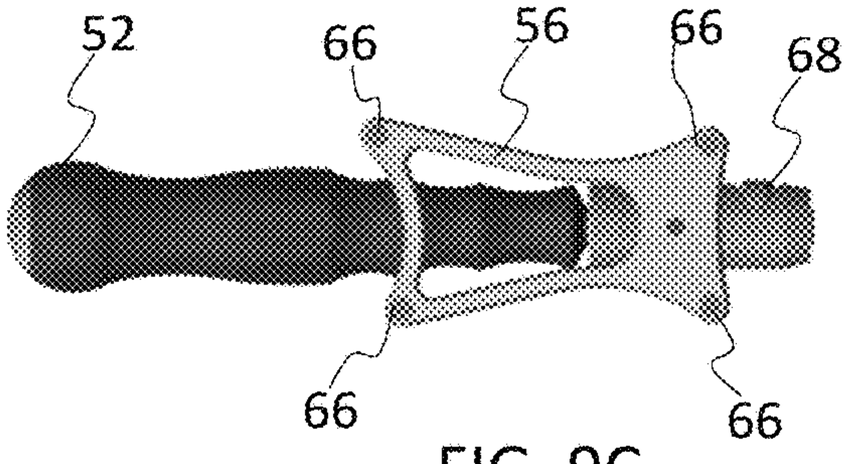


FIG. 9C

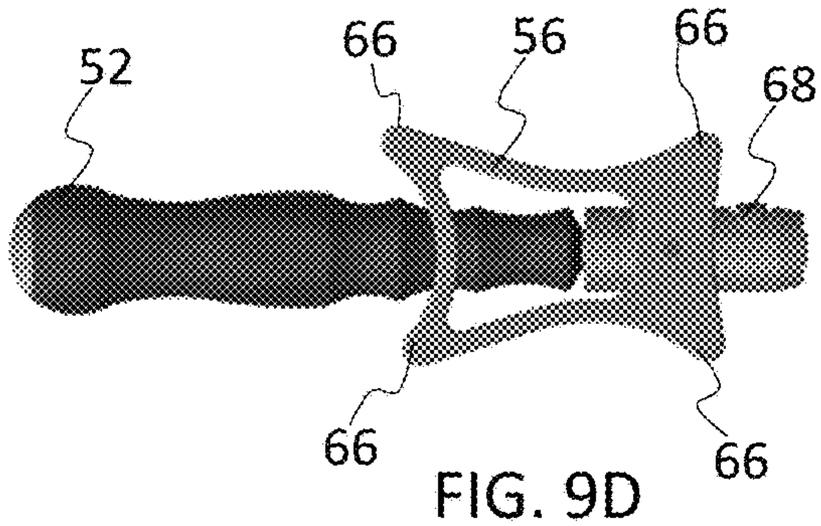


FIG. 9D

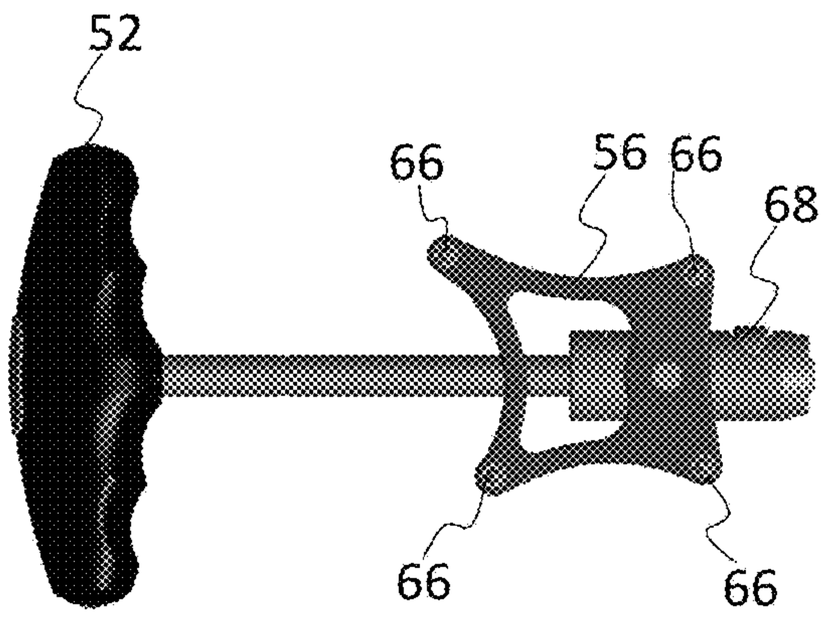


FIG. 9E

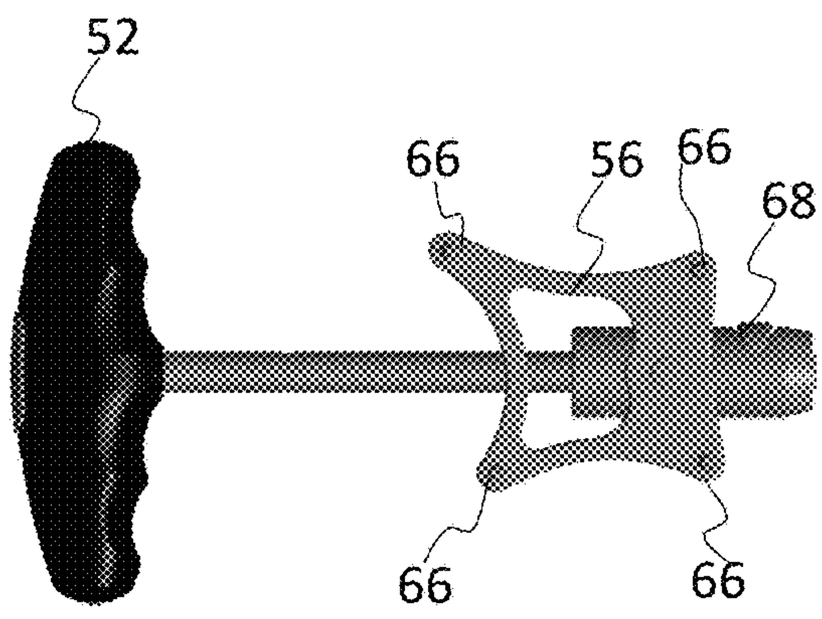


FIG. 9F

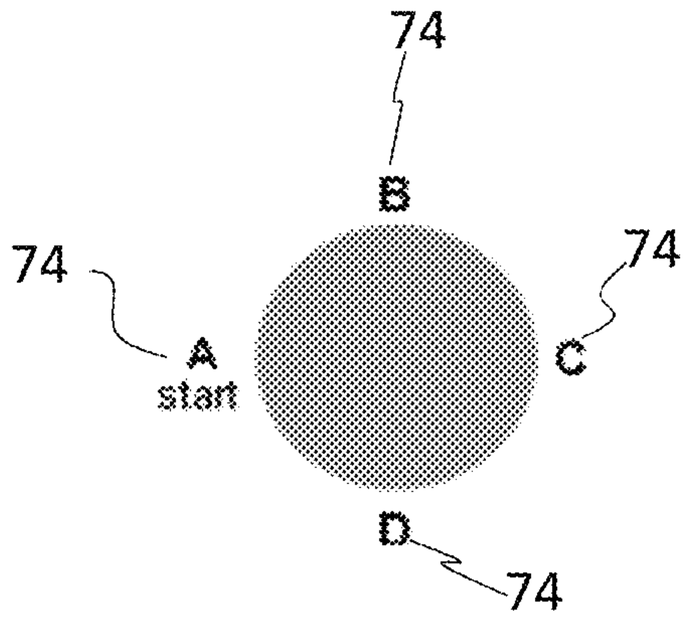


FIG. 10A

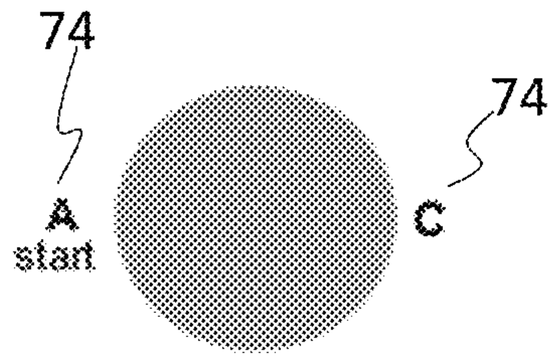


FIG. 10B

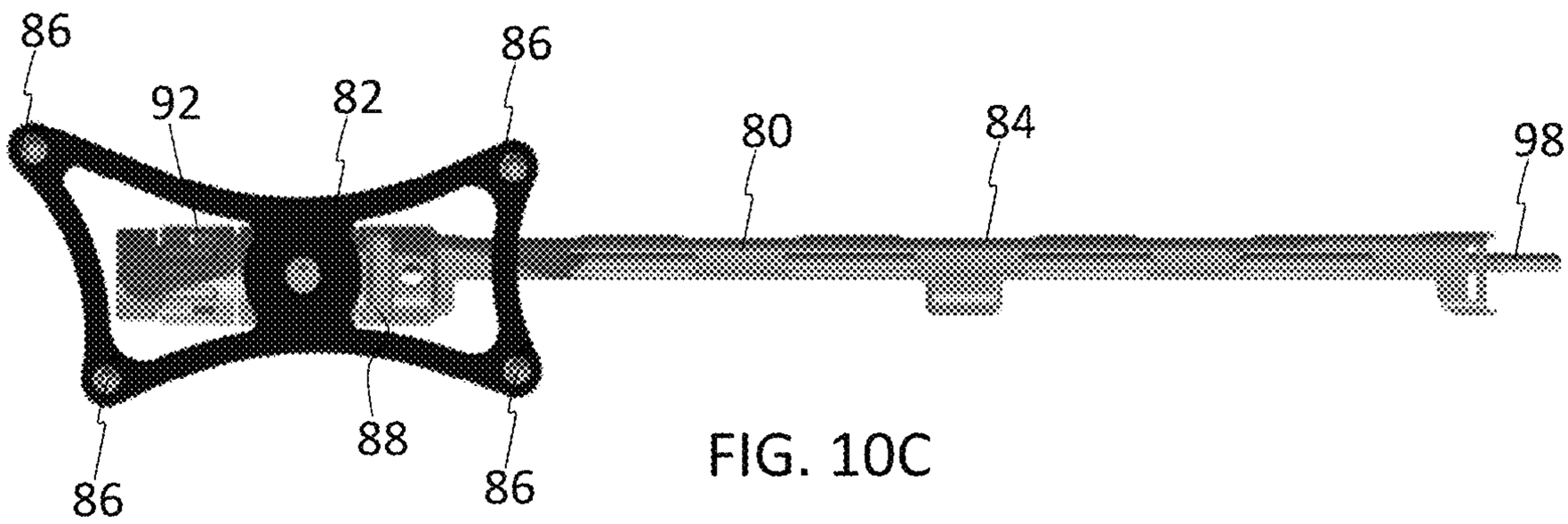


FIG. 10C

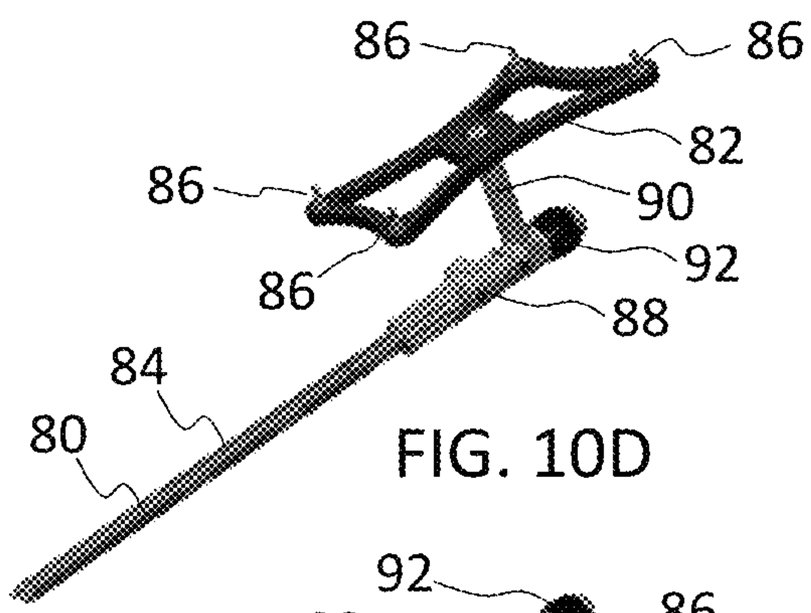


FIG. 10D

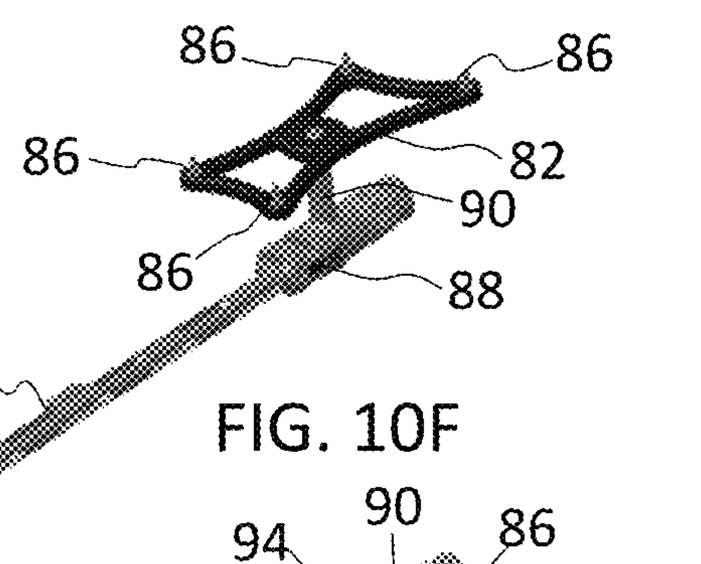


FIG. 10F

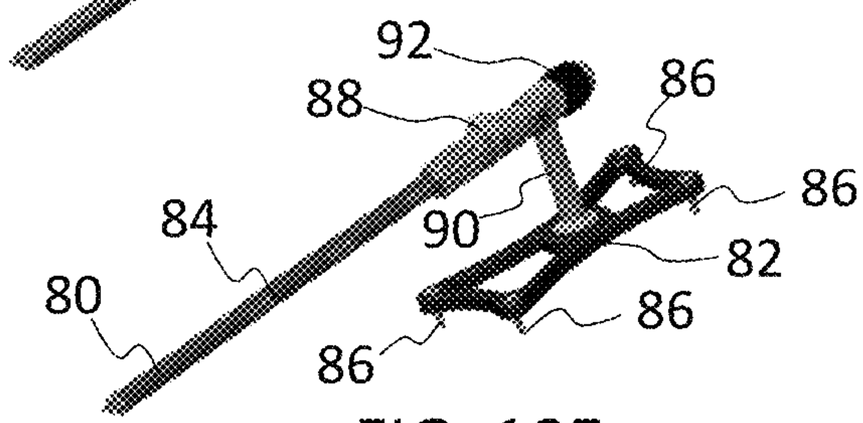


FIG. 10E

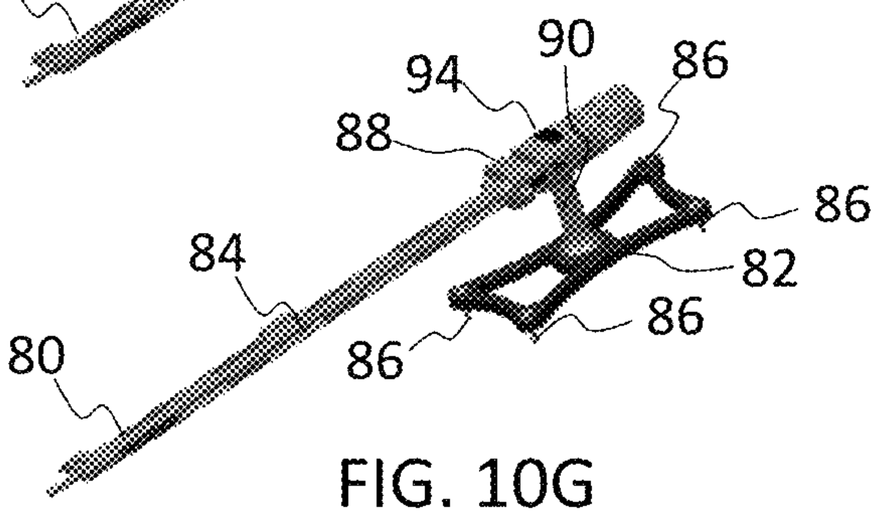


FIG. 10G

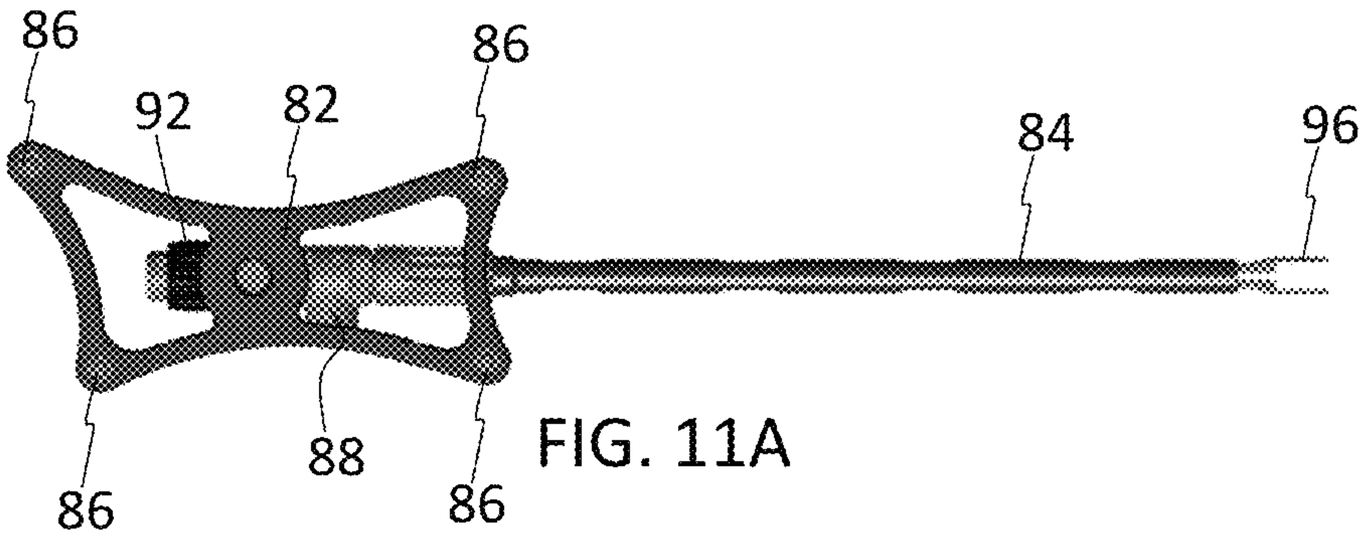


FIG. 11A

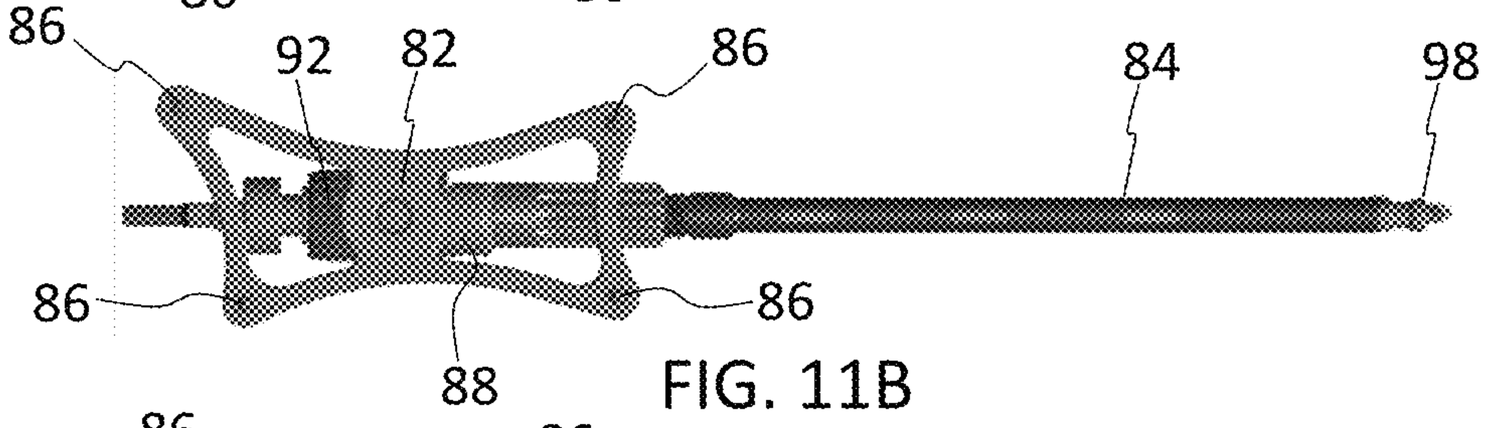


FIG. 11B

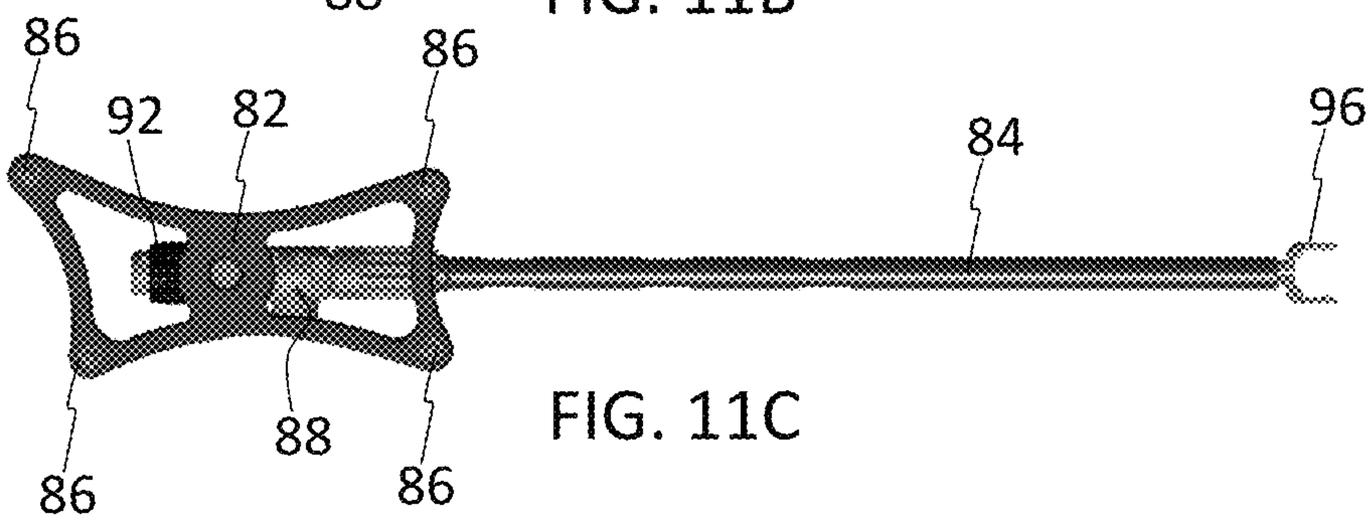


FIG. 11C

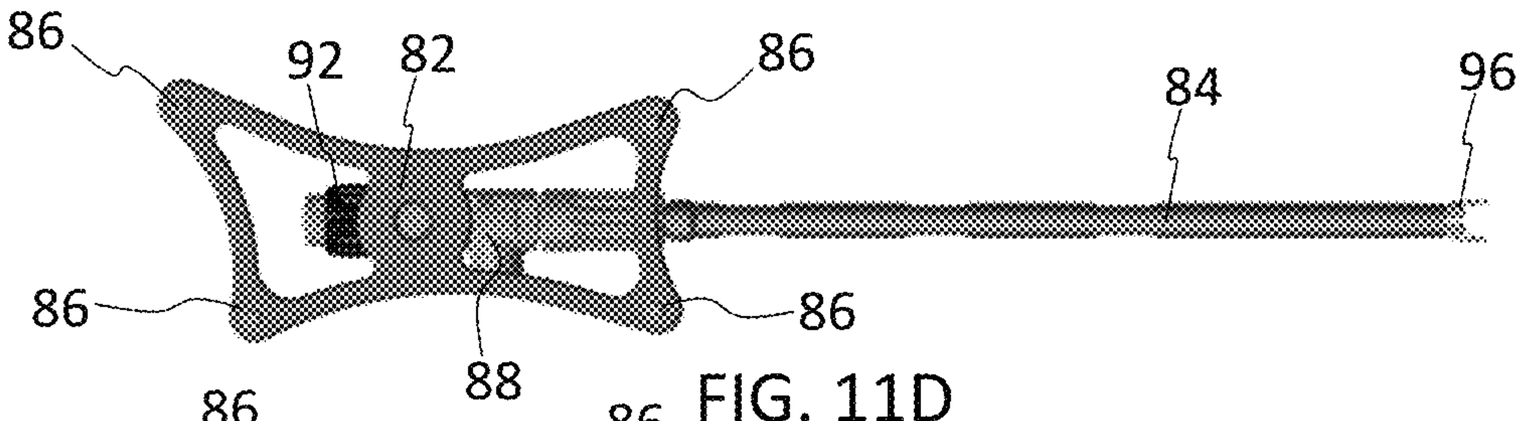


FIG. 11D

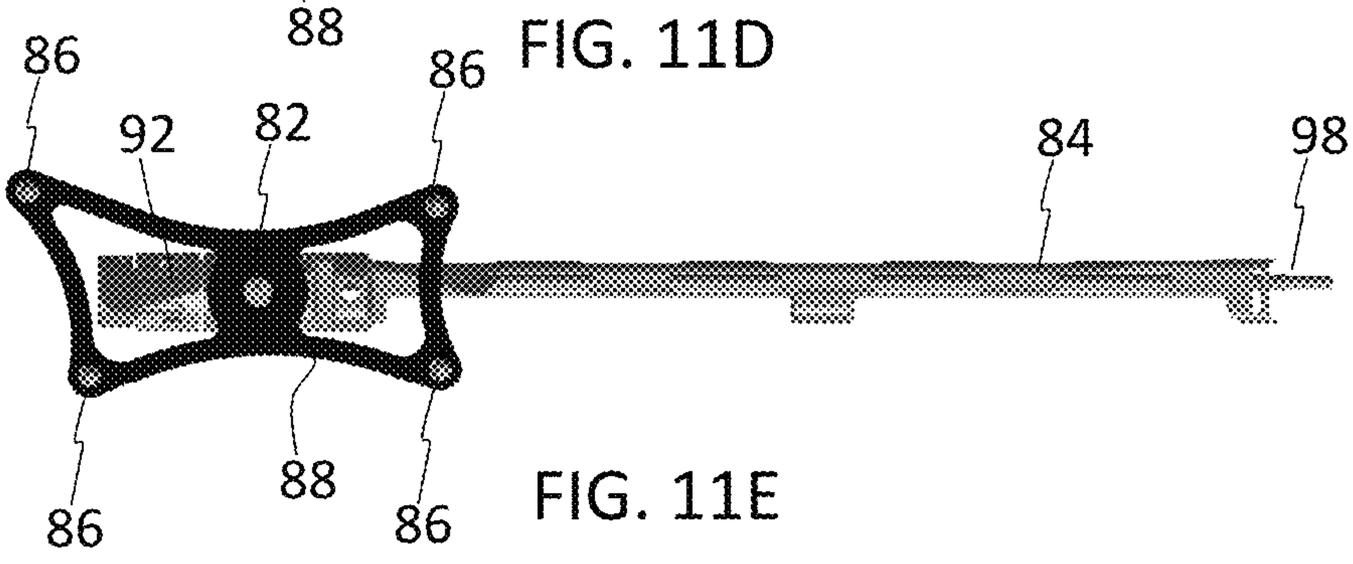


FIG. 11E

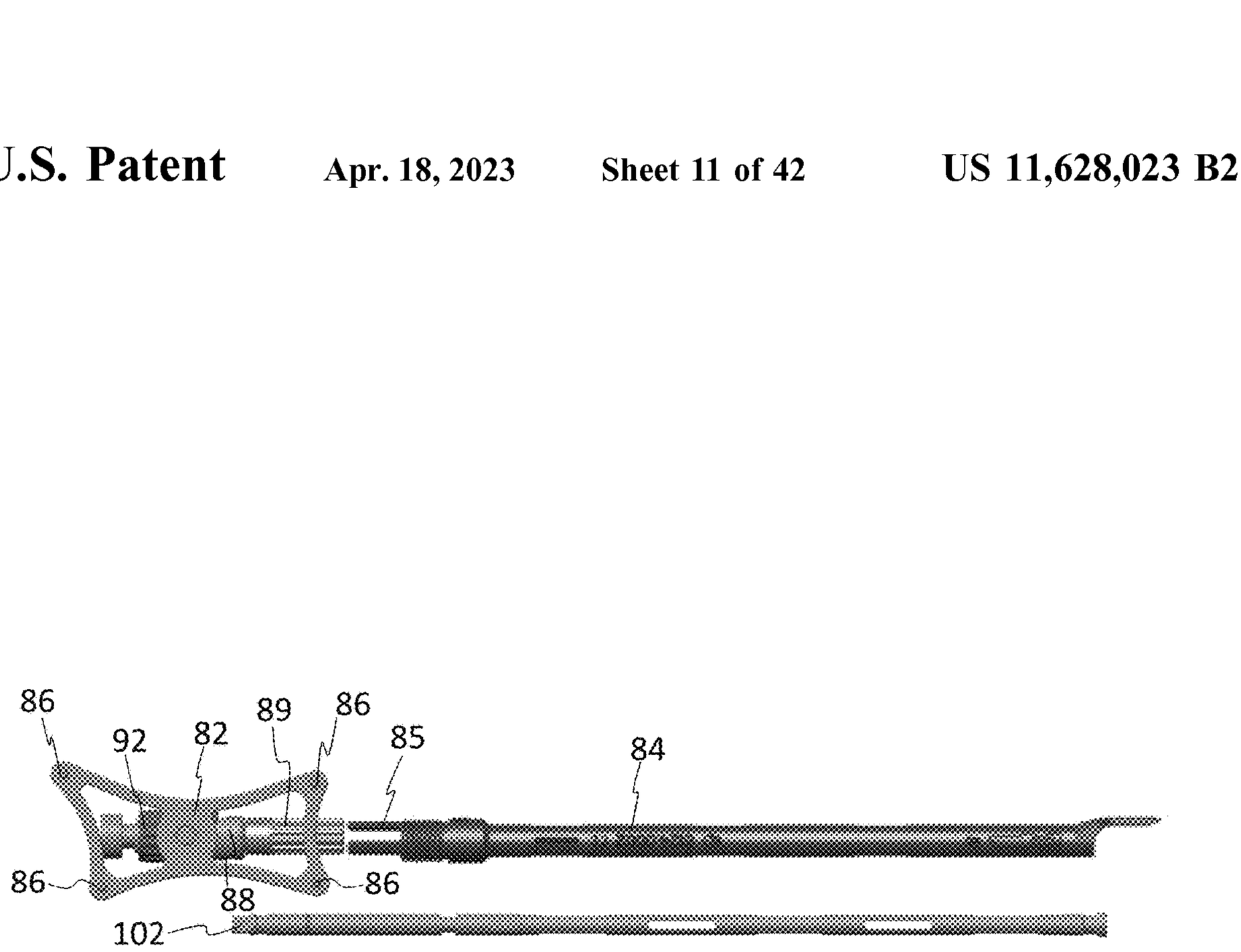


FIG. 12A

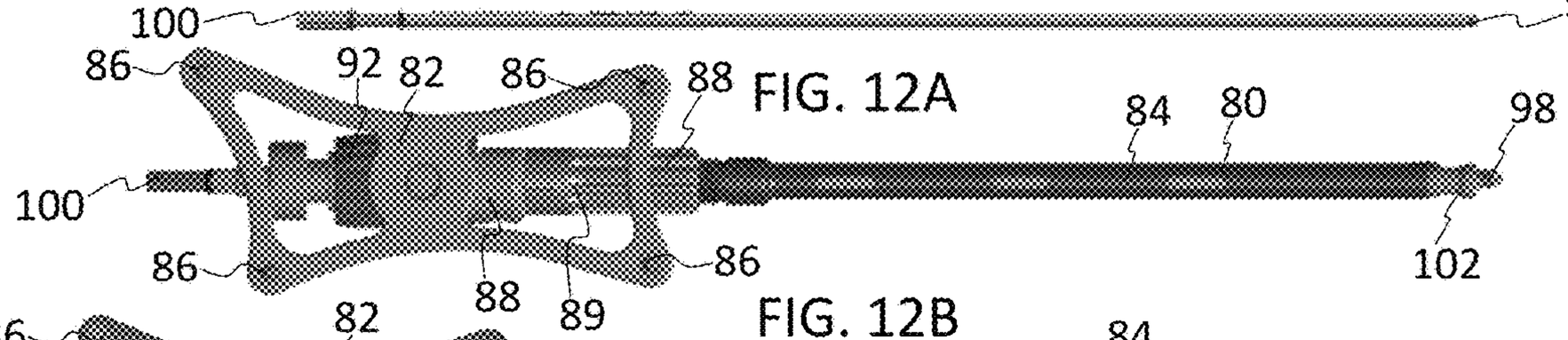


FIG. 12B

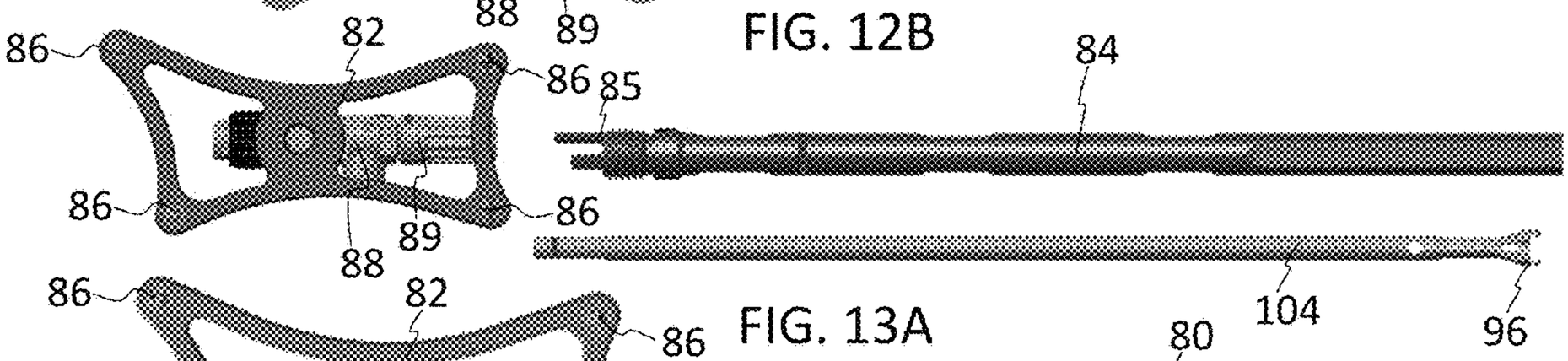


FIG. 13A

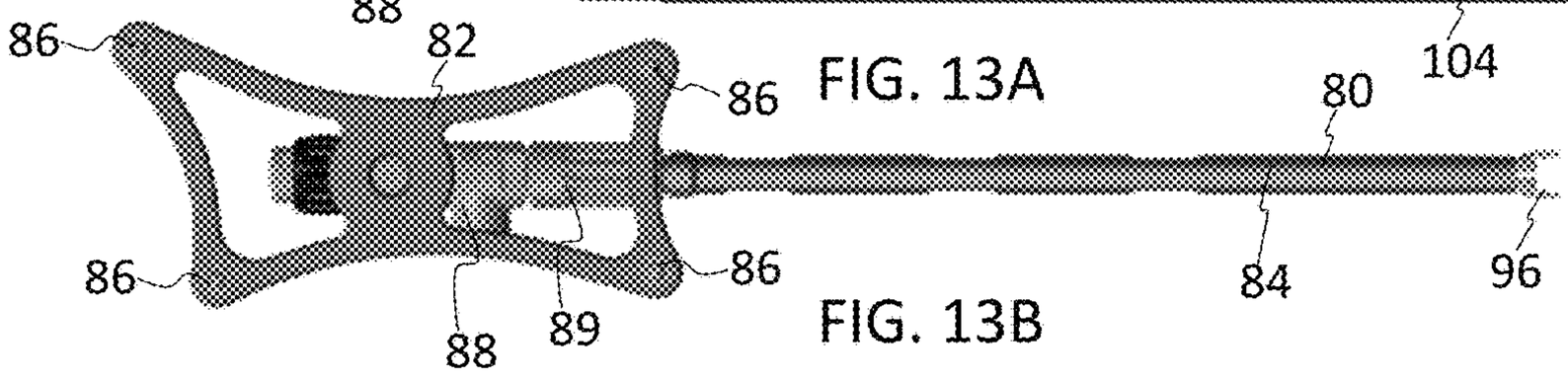


FIG. 13B

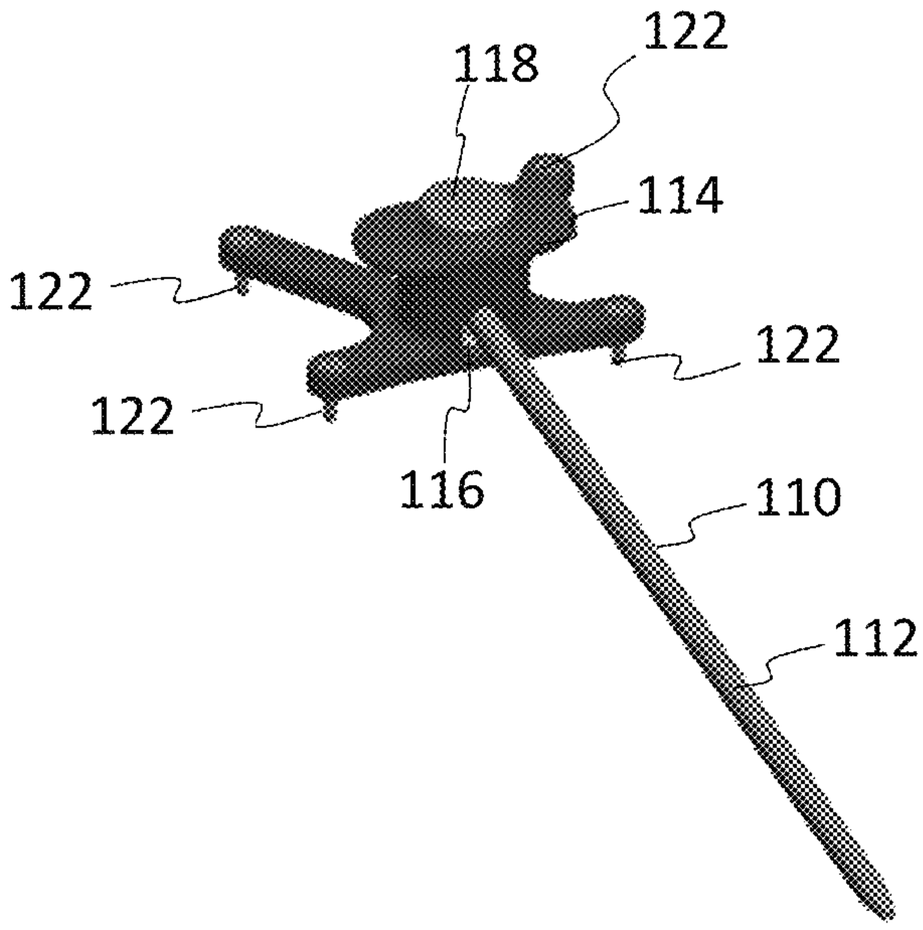


FIG. 14A

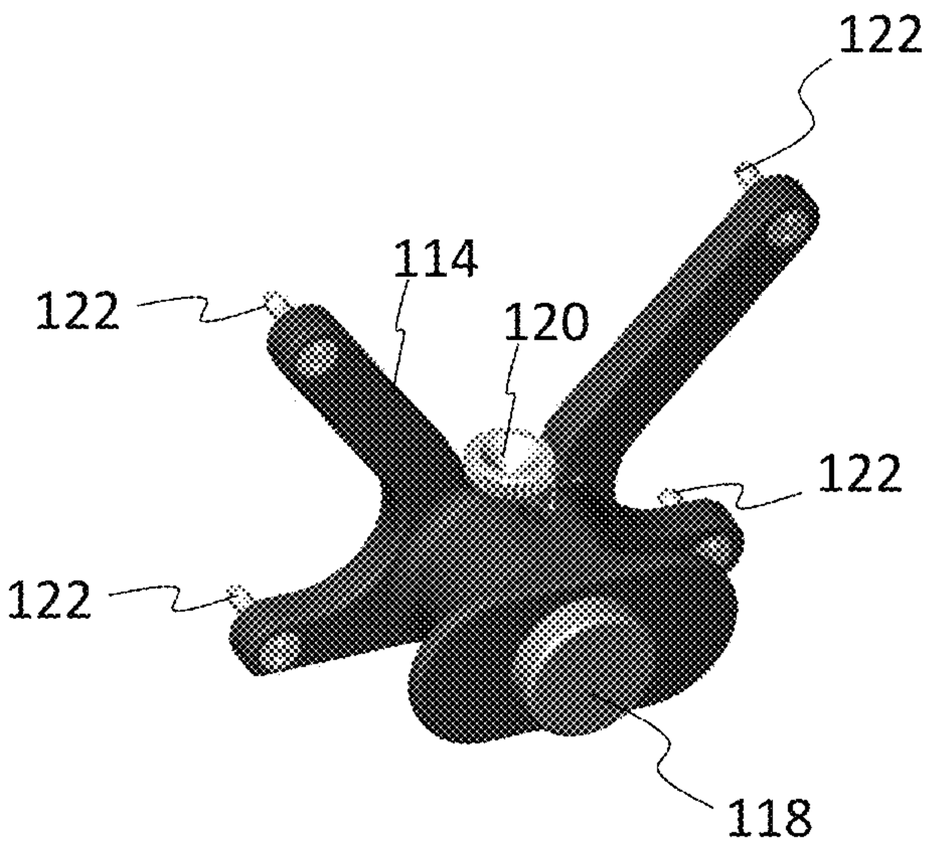


FIG. 14B

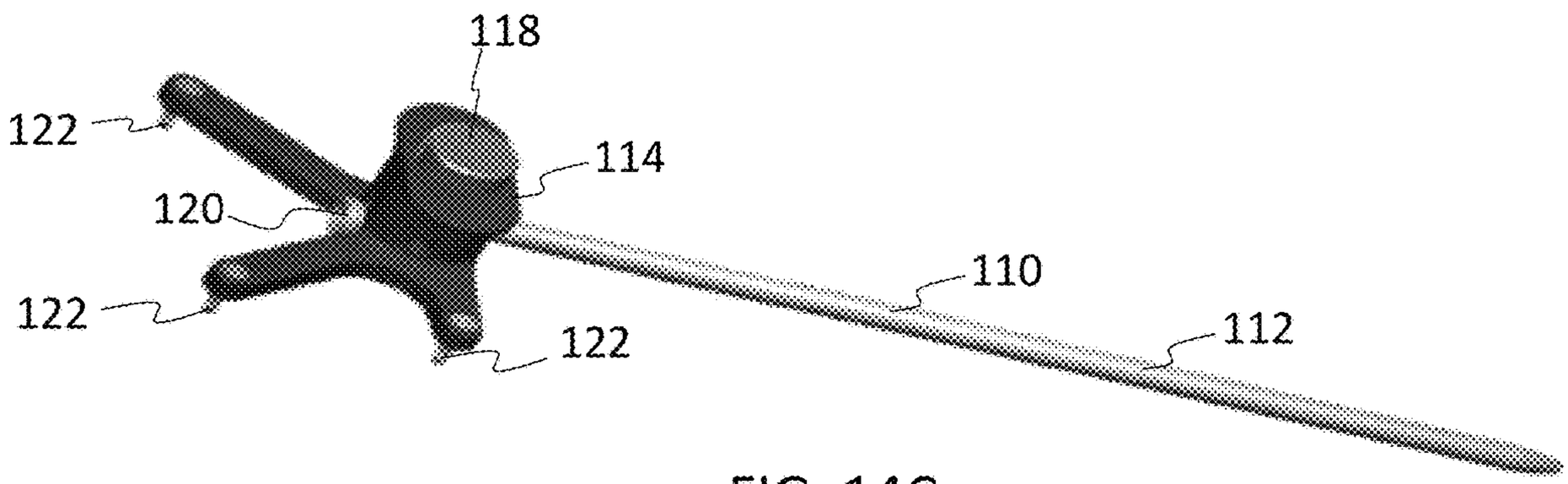


FIG. 14C

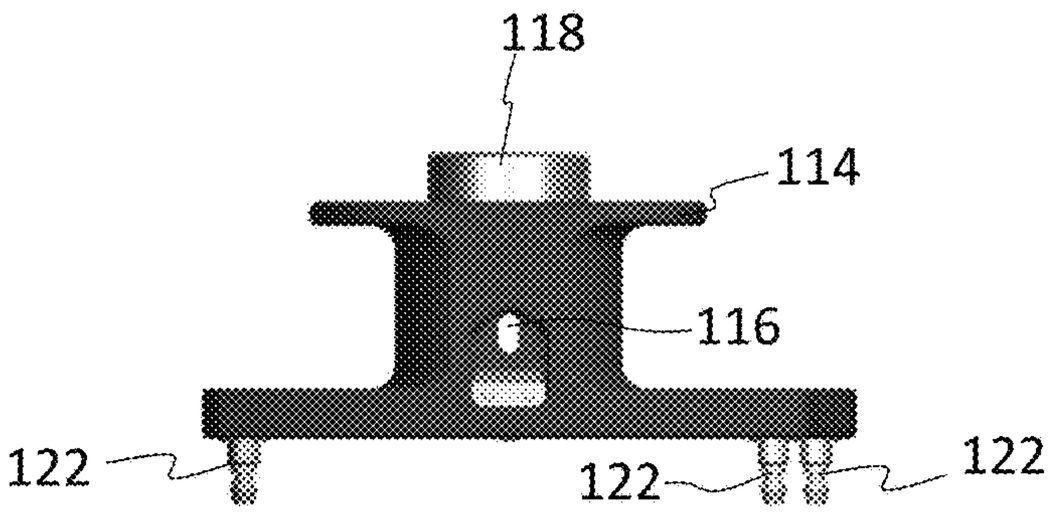


FIG. 14D

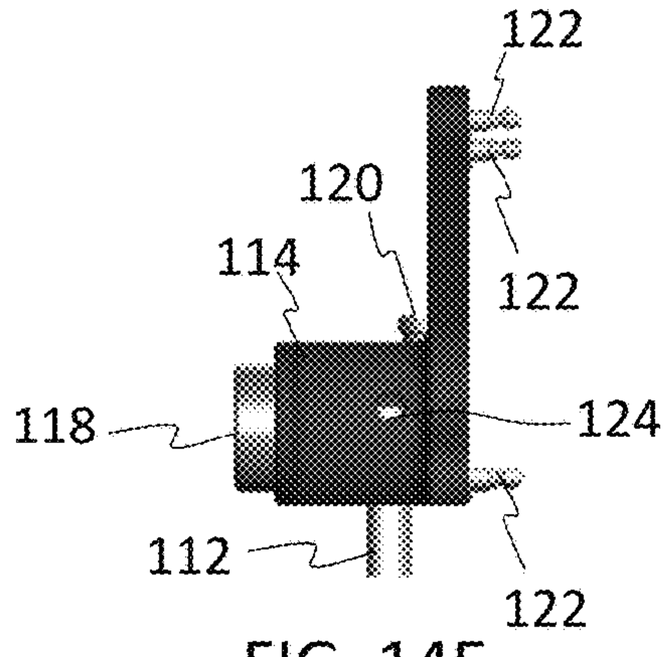


FIG. 14E

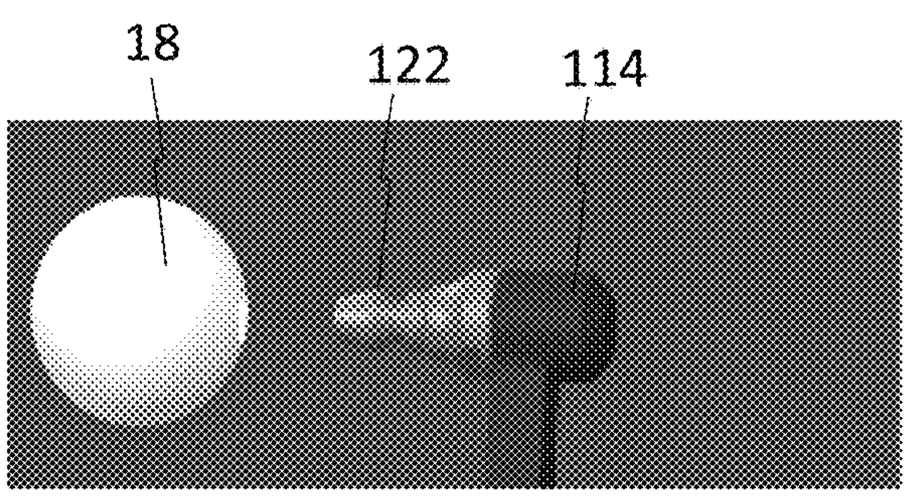


FIG. 14F

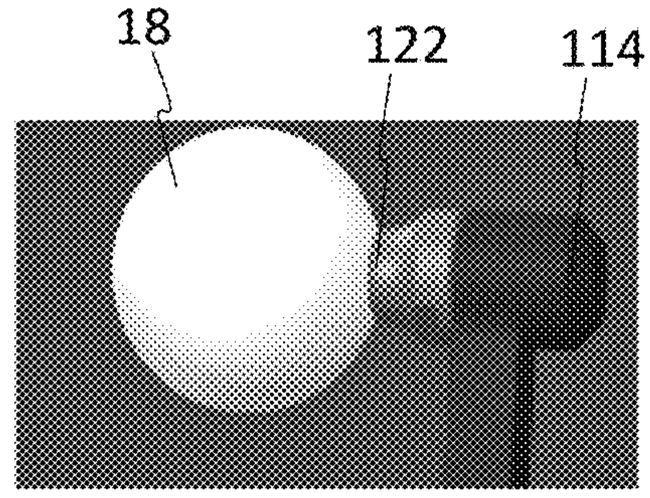


FIG. 14G

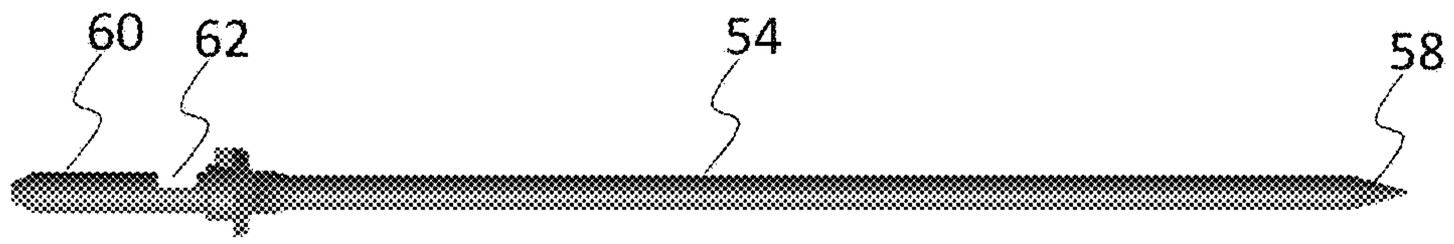


FIG. 15A

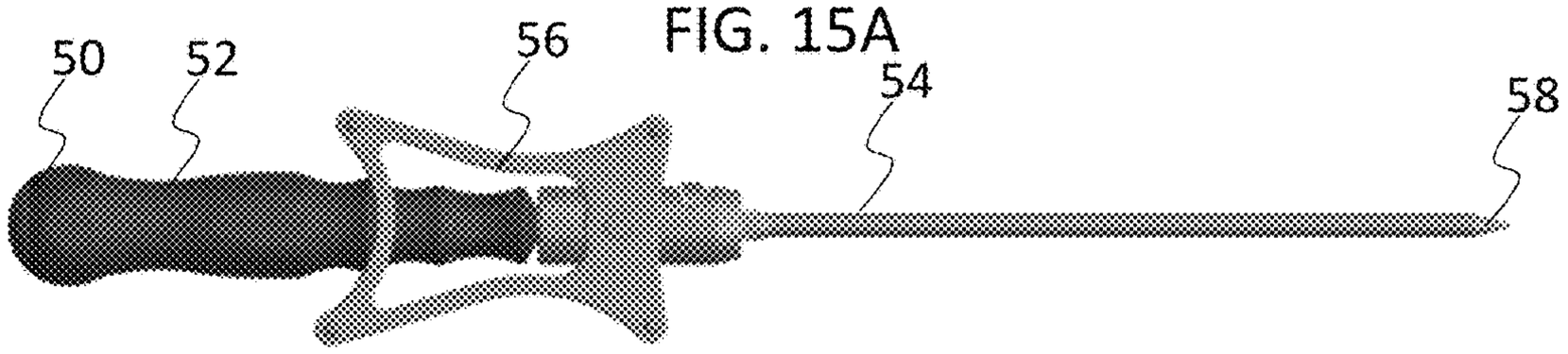


FIG. 15B

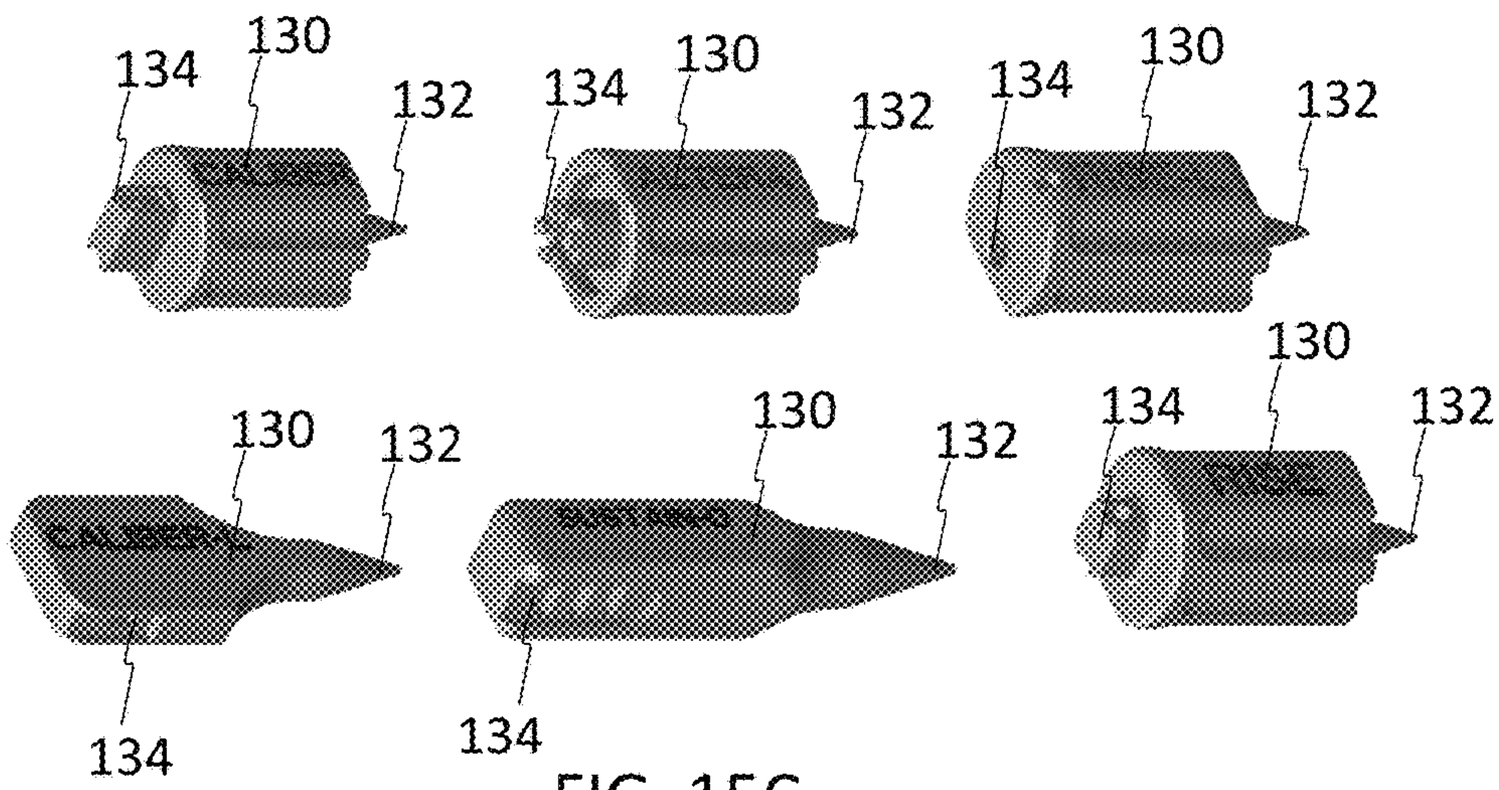


FIG. 15C

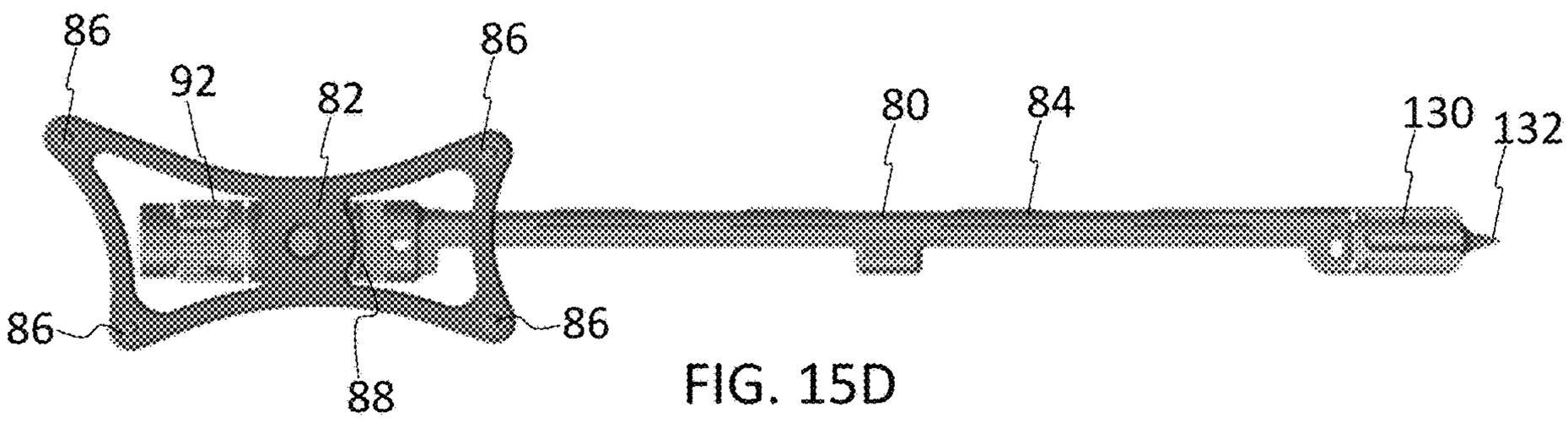


FIG. 15D

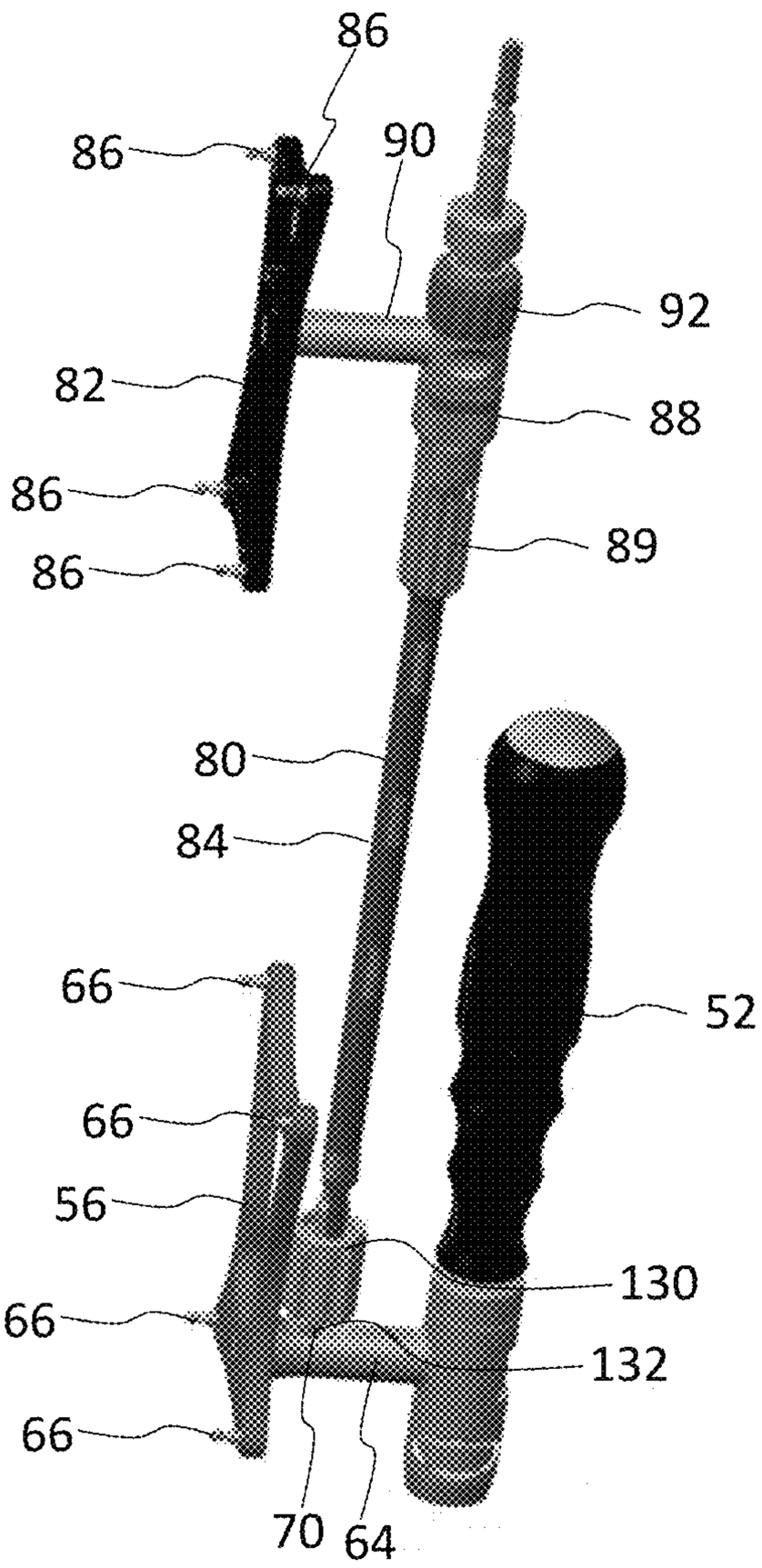


FIG. 16A

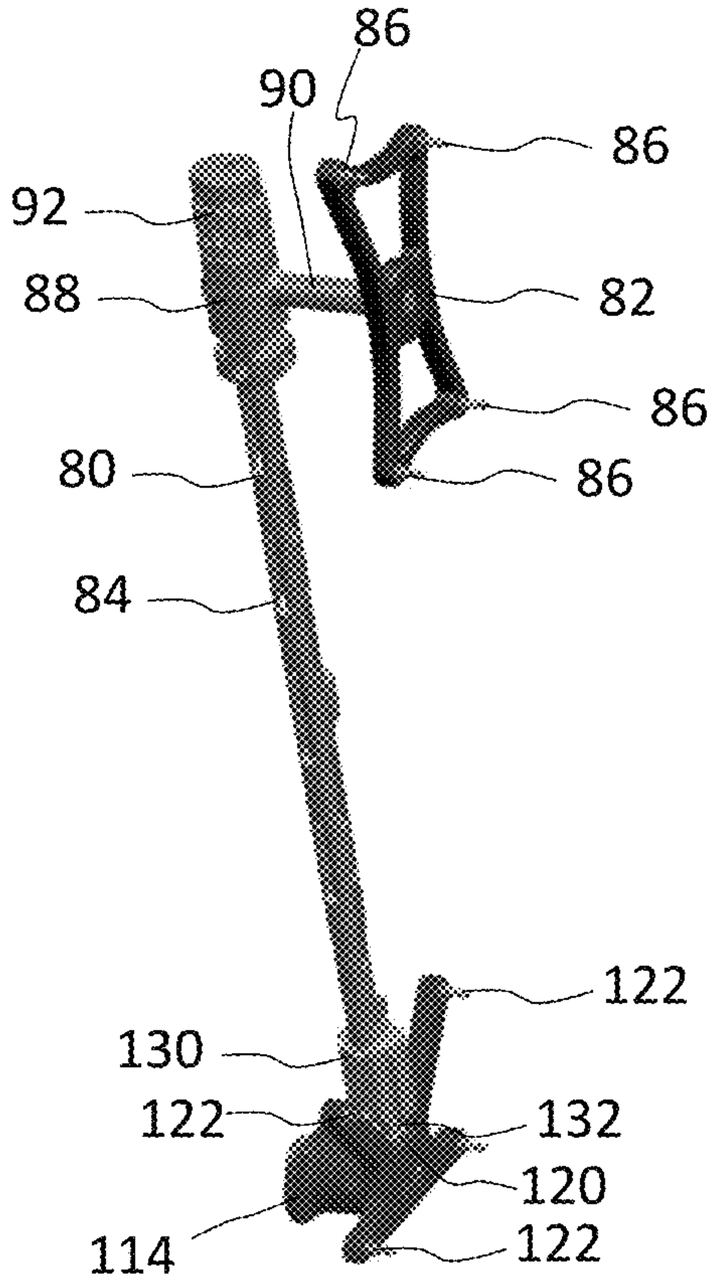


FIG. 16B

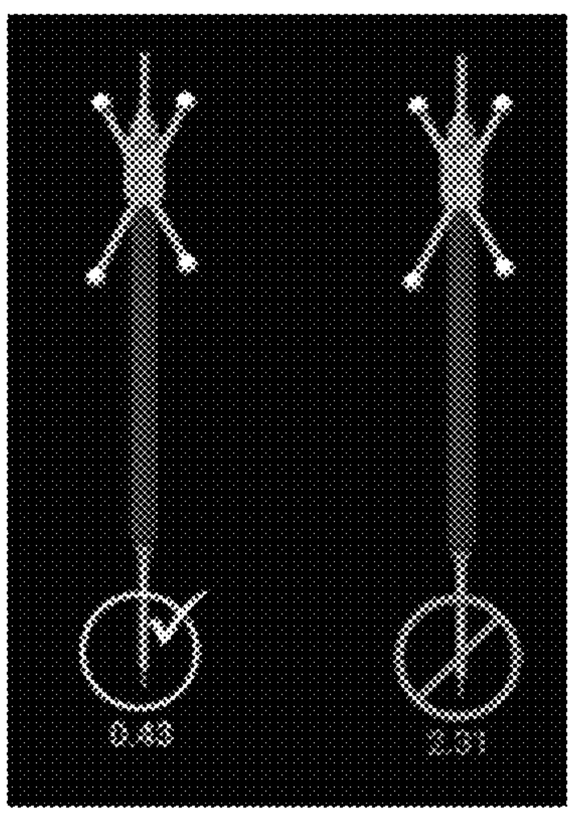


FIG. 16C

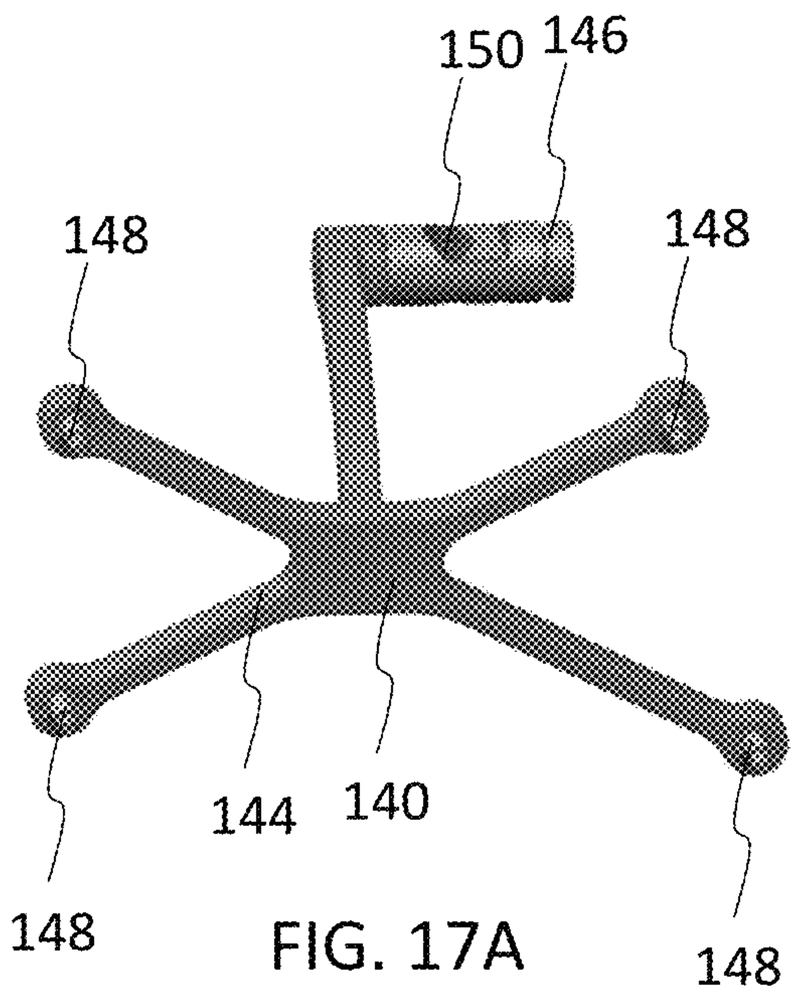


FIG. 17A

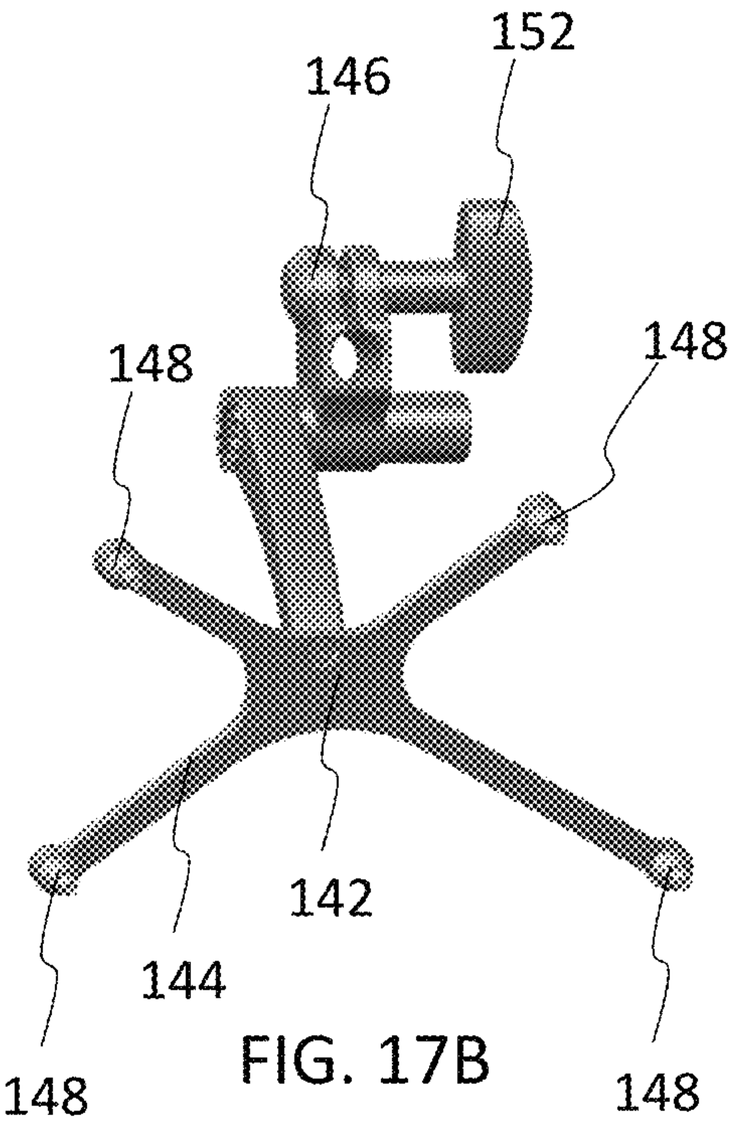


FIG. 17B

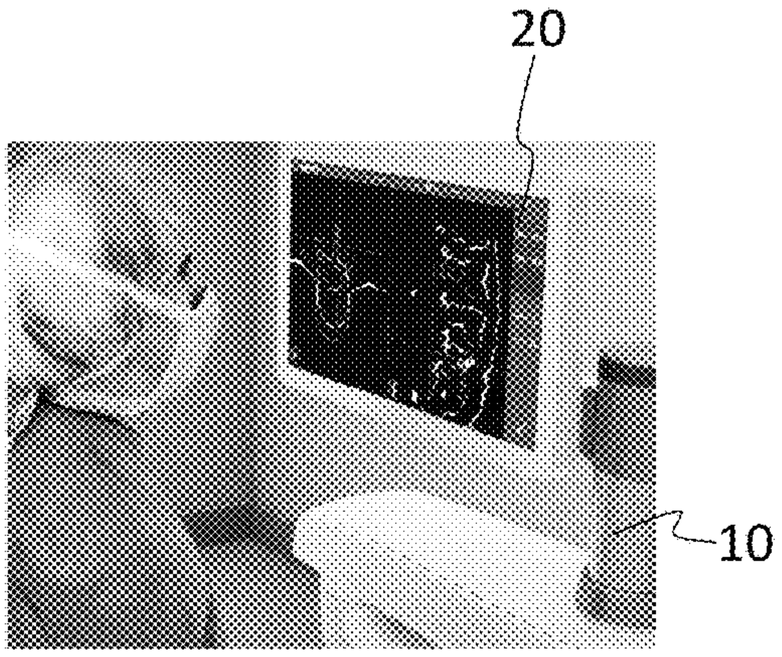


FIG. 18A

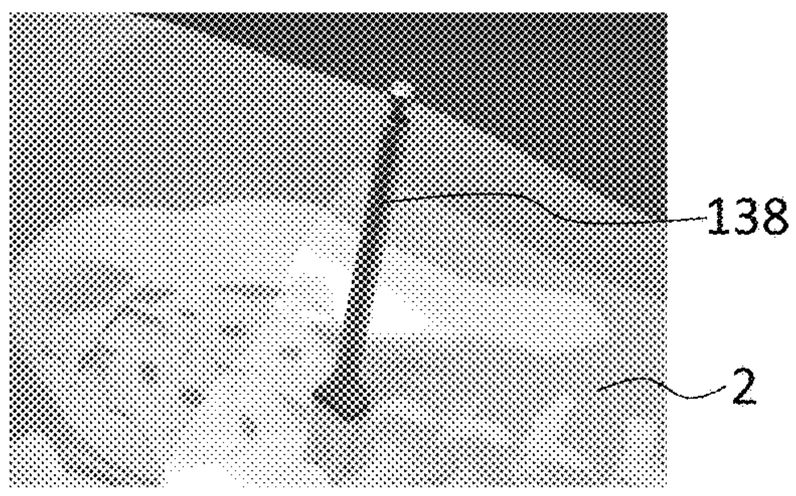


FIG. 18B

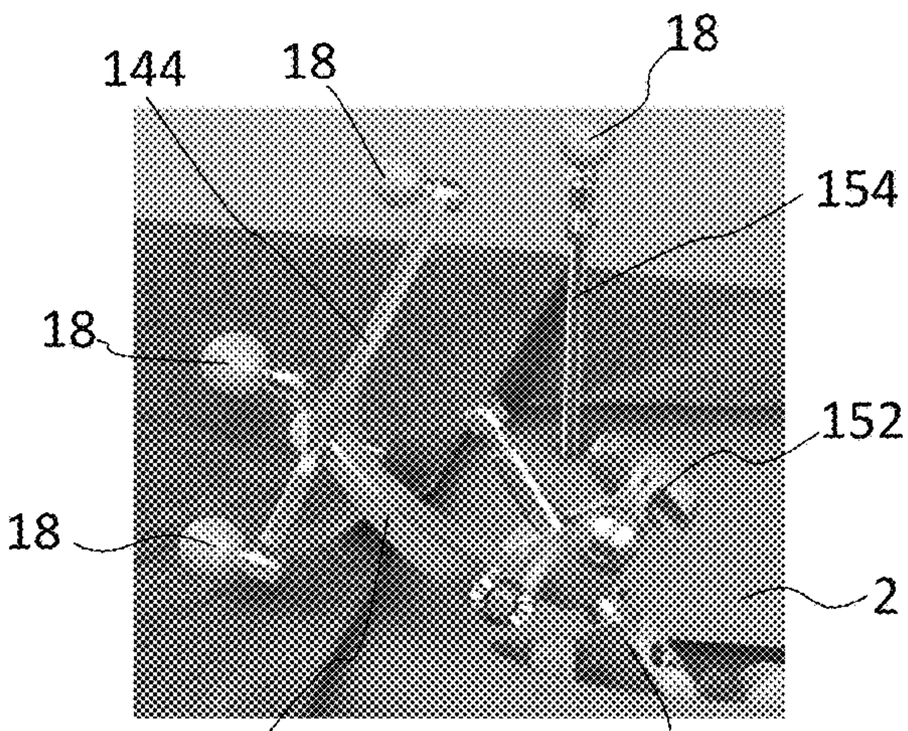


FIG. 18C

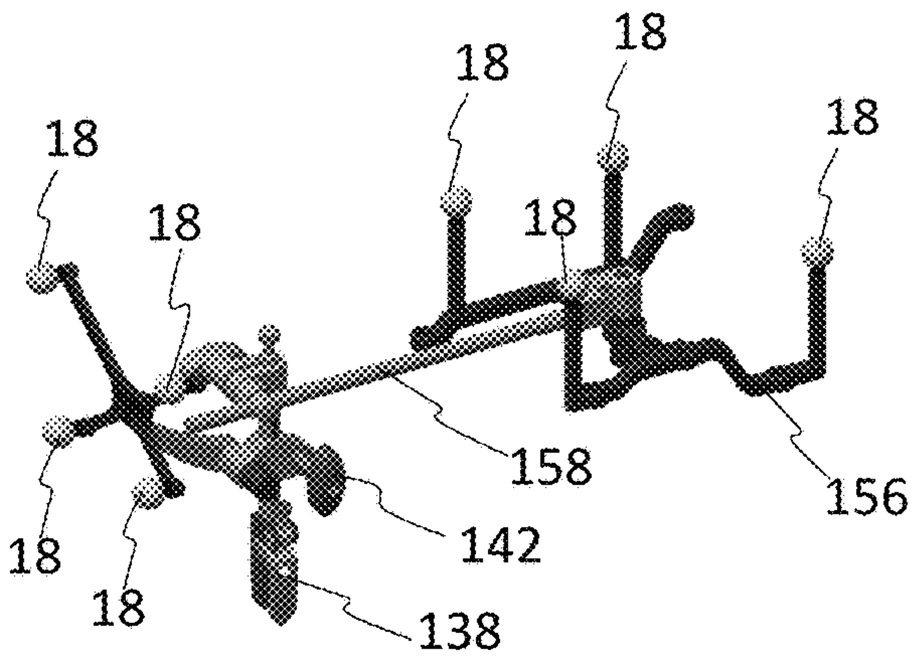


FIG. 18D

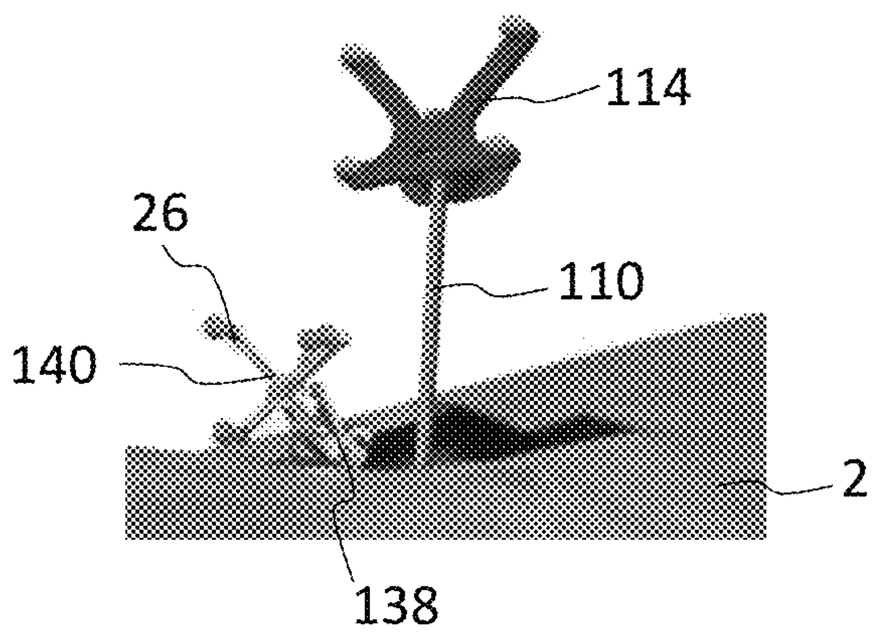


FIG. 19A

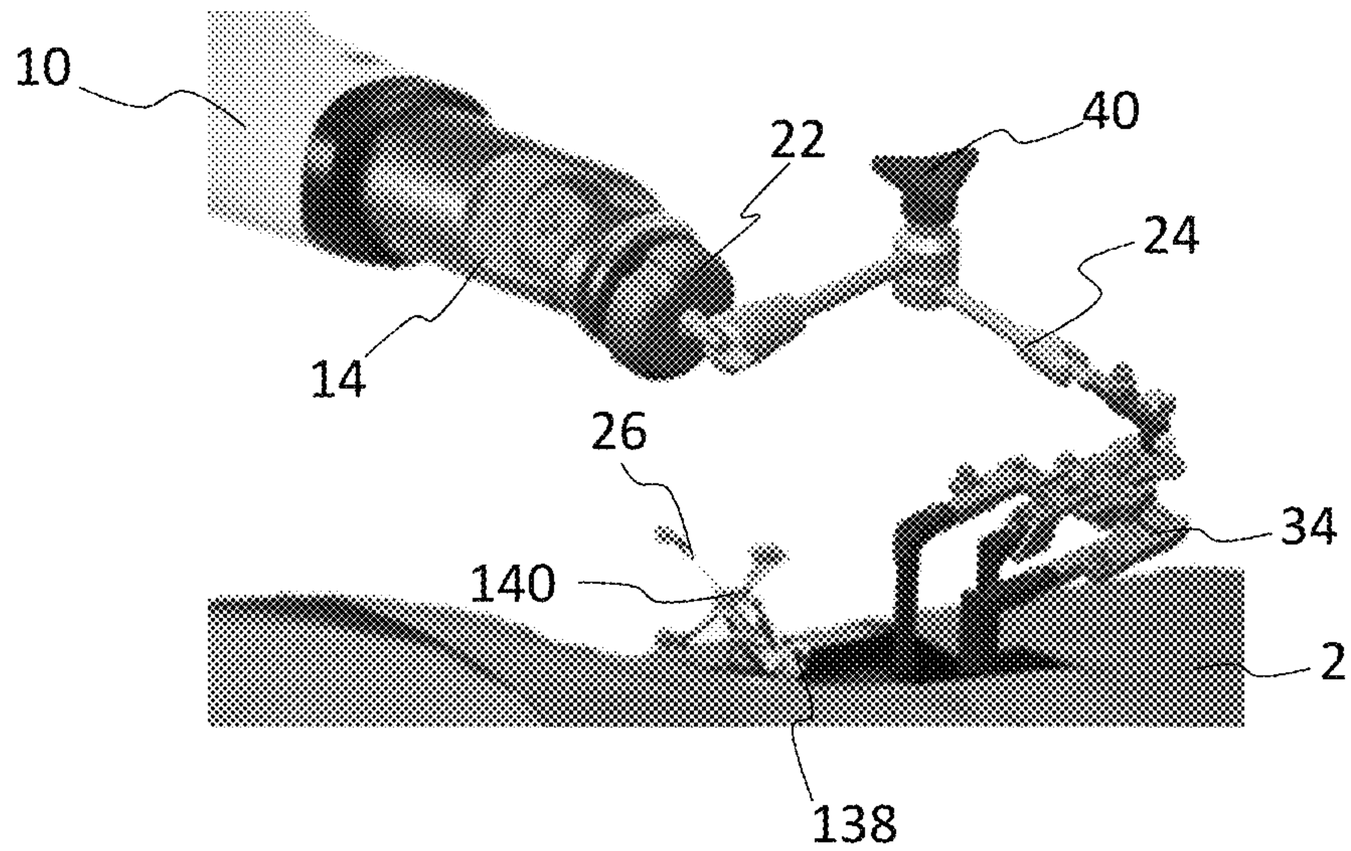


FIG. 19B

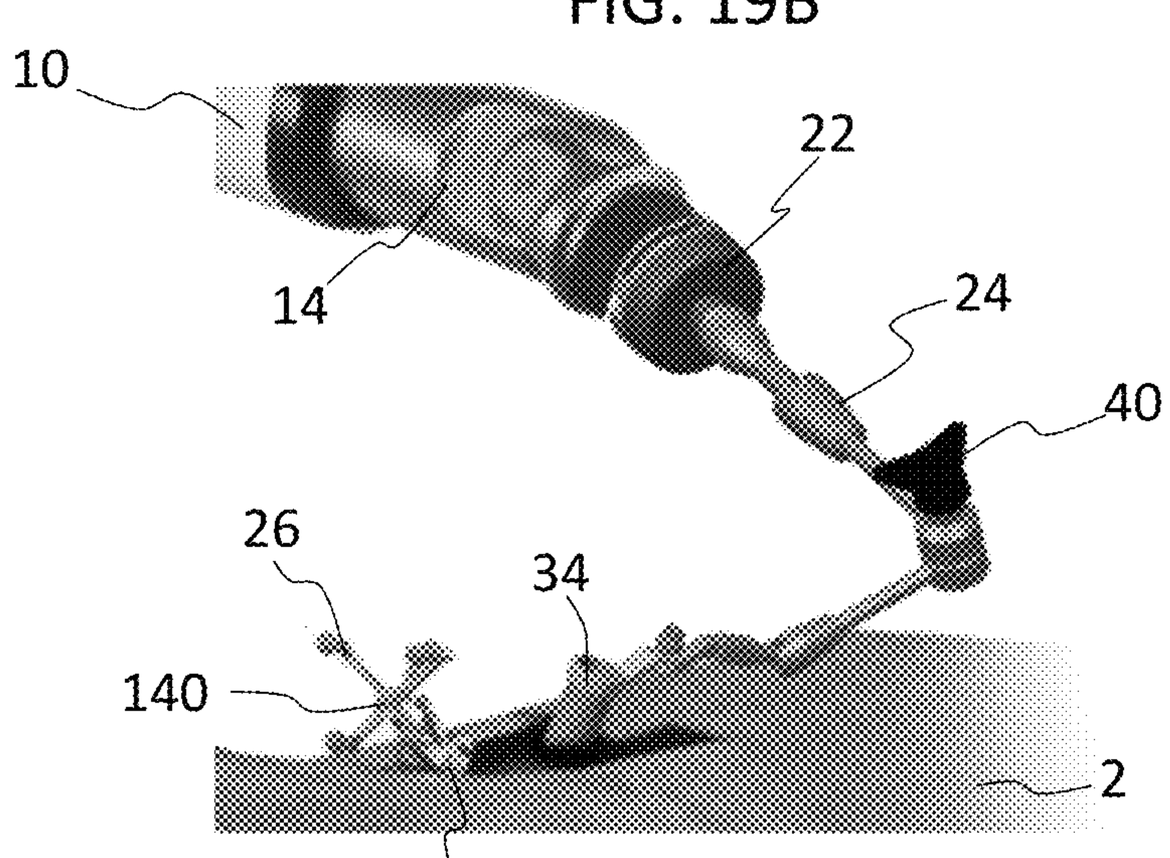


FIG. 19C

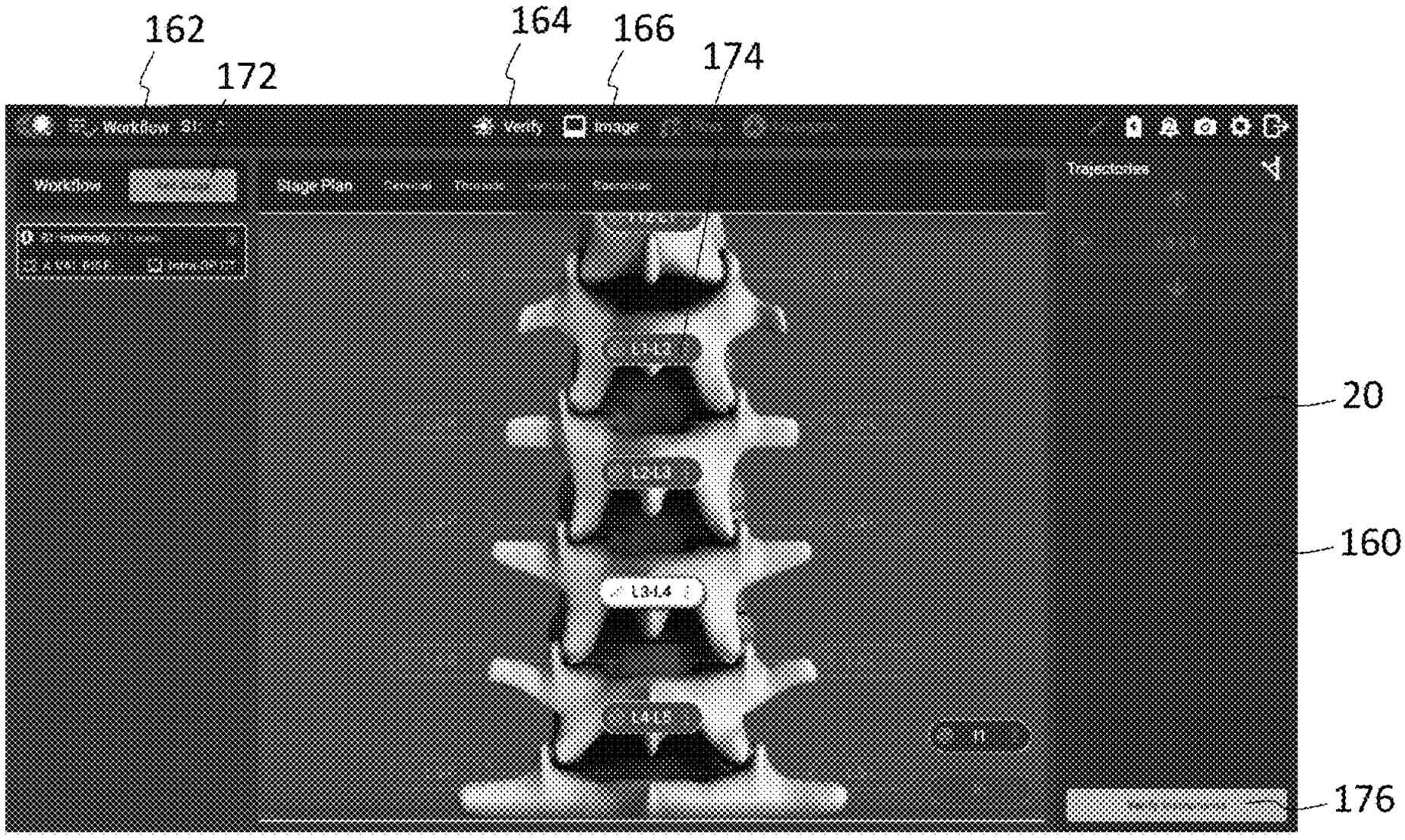


FIG. 20A

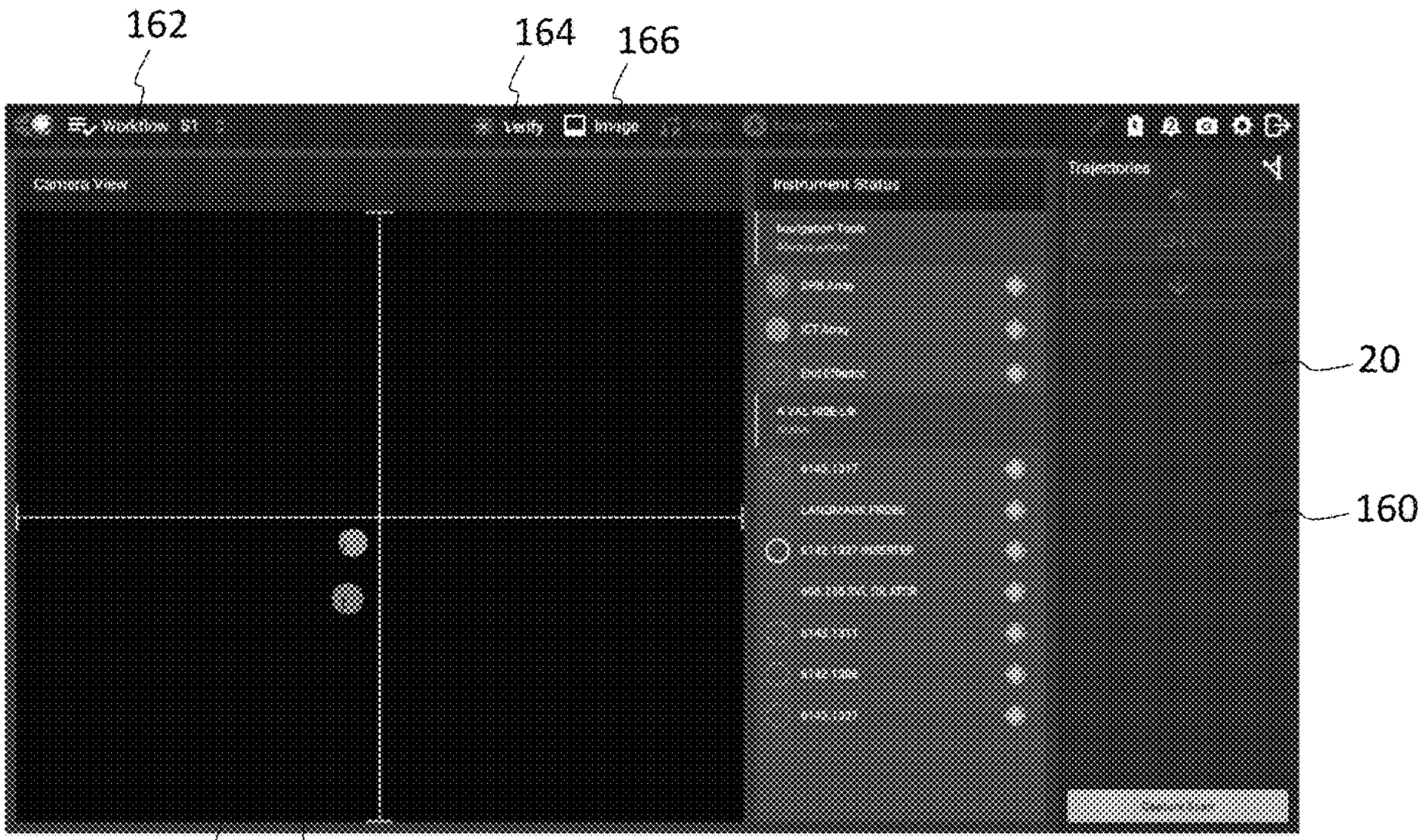
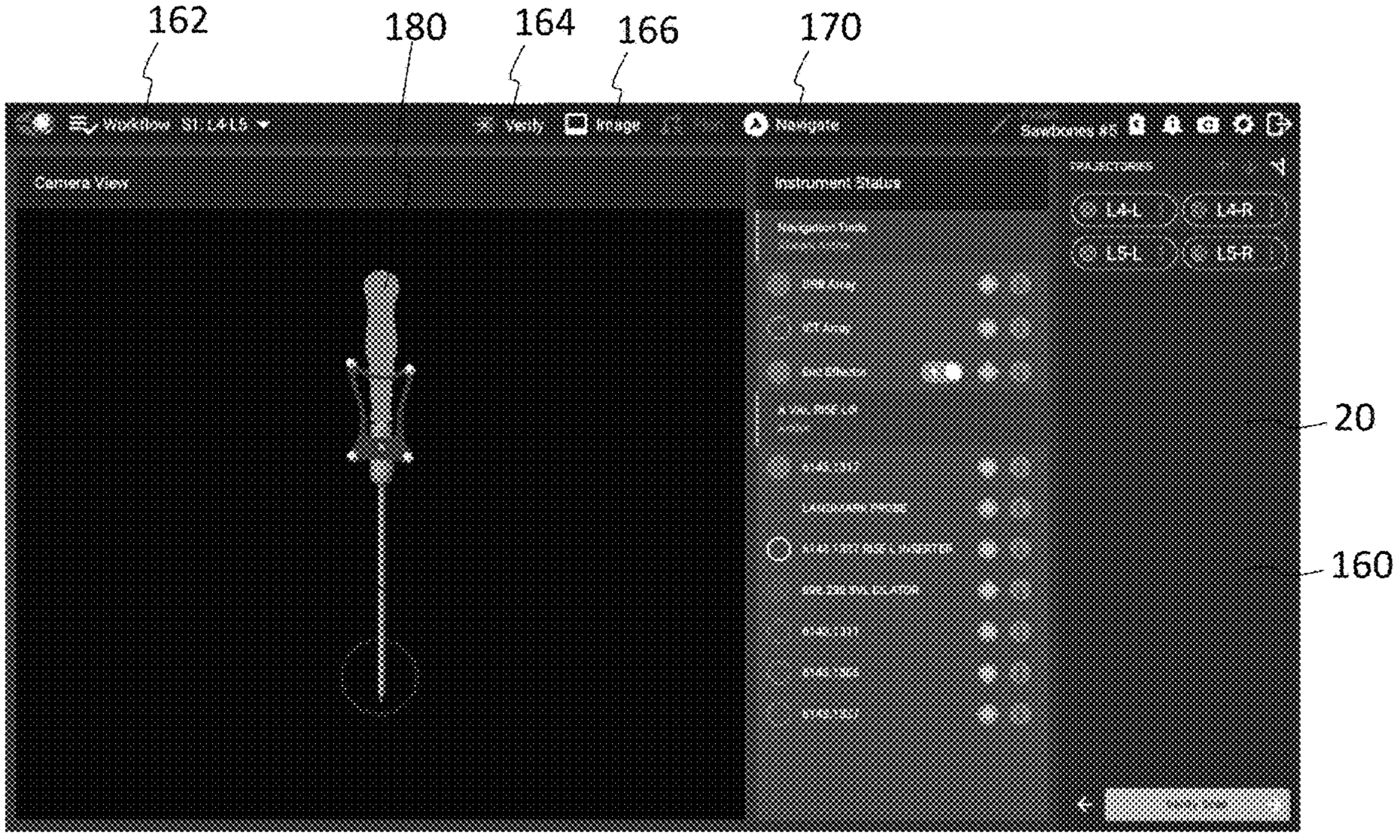


FIG. 20B


162
180
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166
170
Workflow: ST LA-LS
Verify
Image
Navigate
Sandboxes: 0/5
Camera View
Instrument Status
LA-L
LA-R
LS-L
LS-R
20
160

FIG. 20C

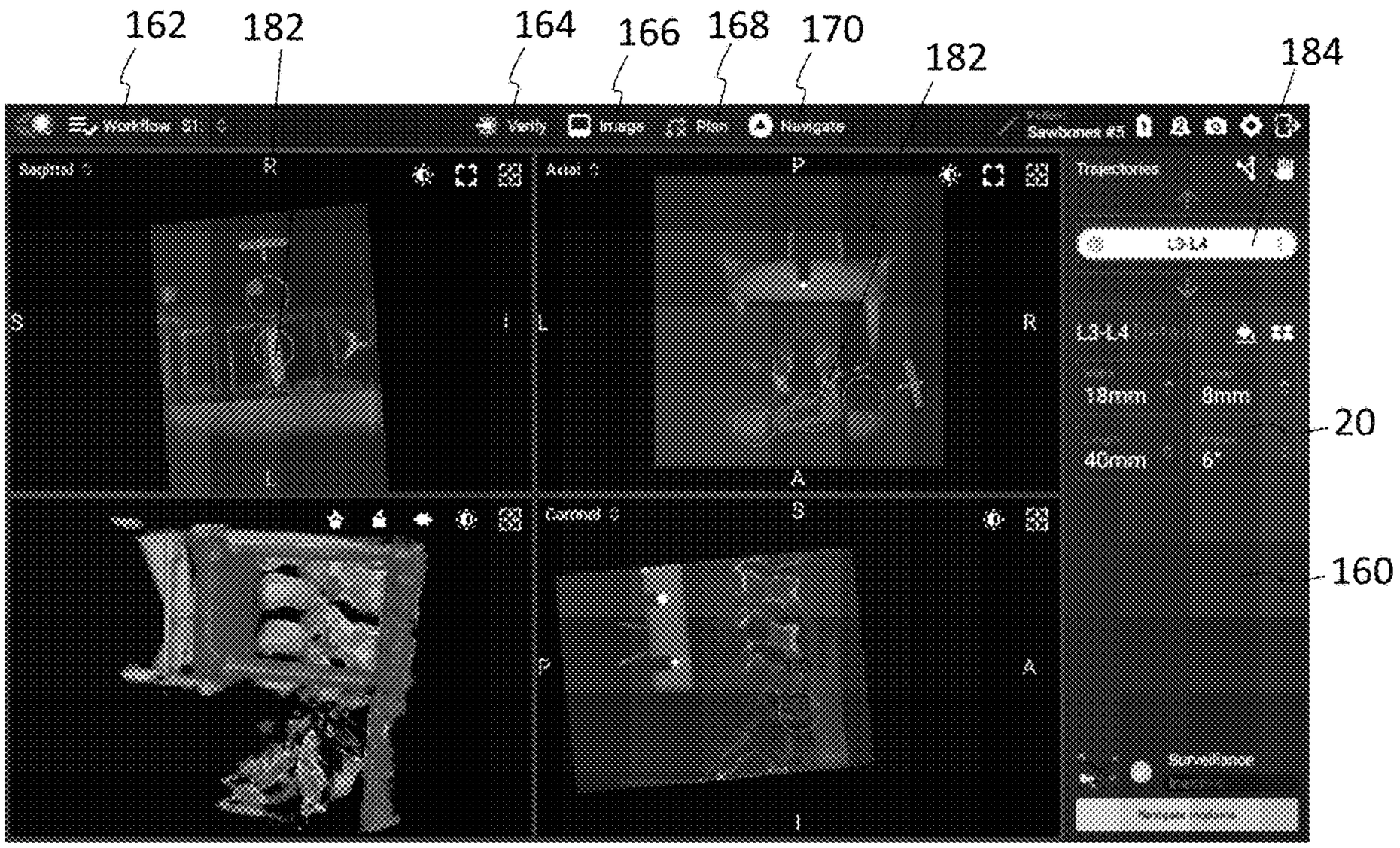

FIG. 20D

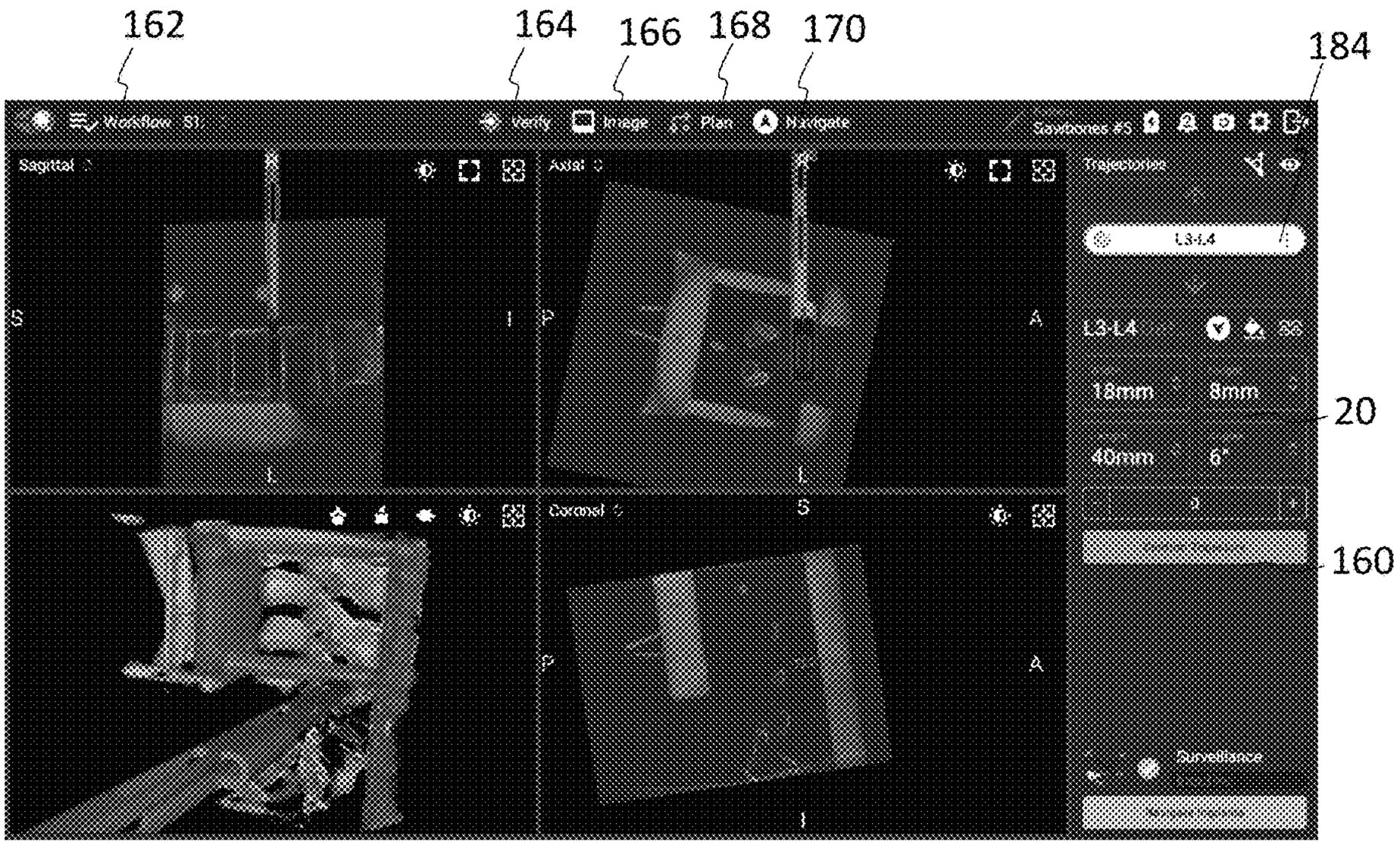

FIG. 20E

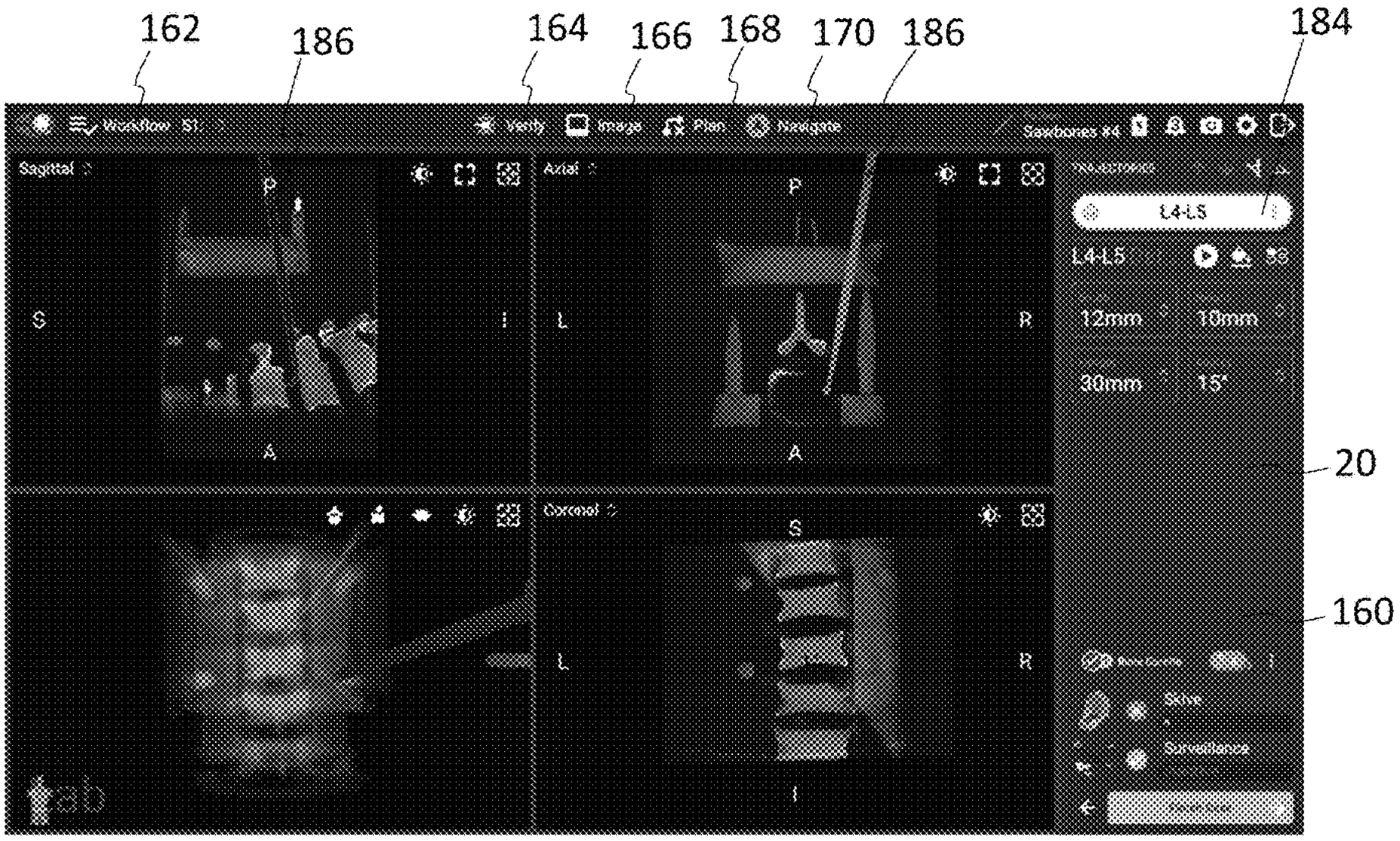

FIG. 20F

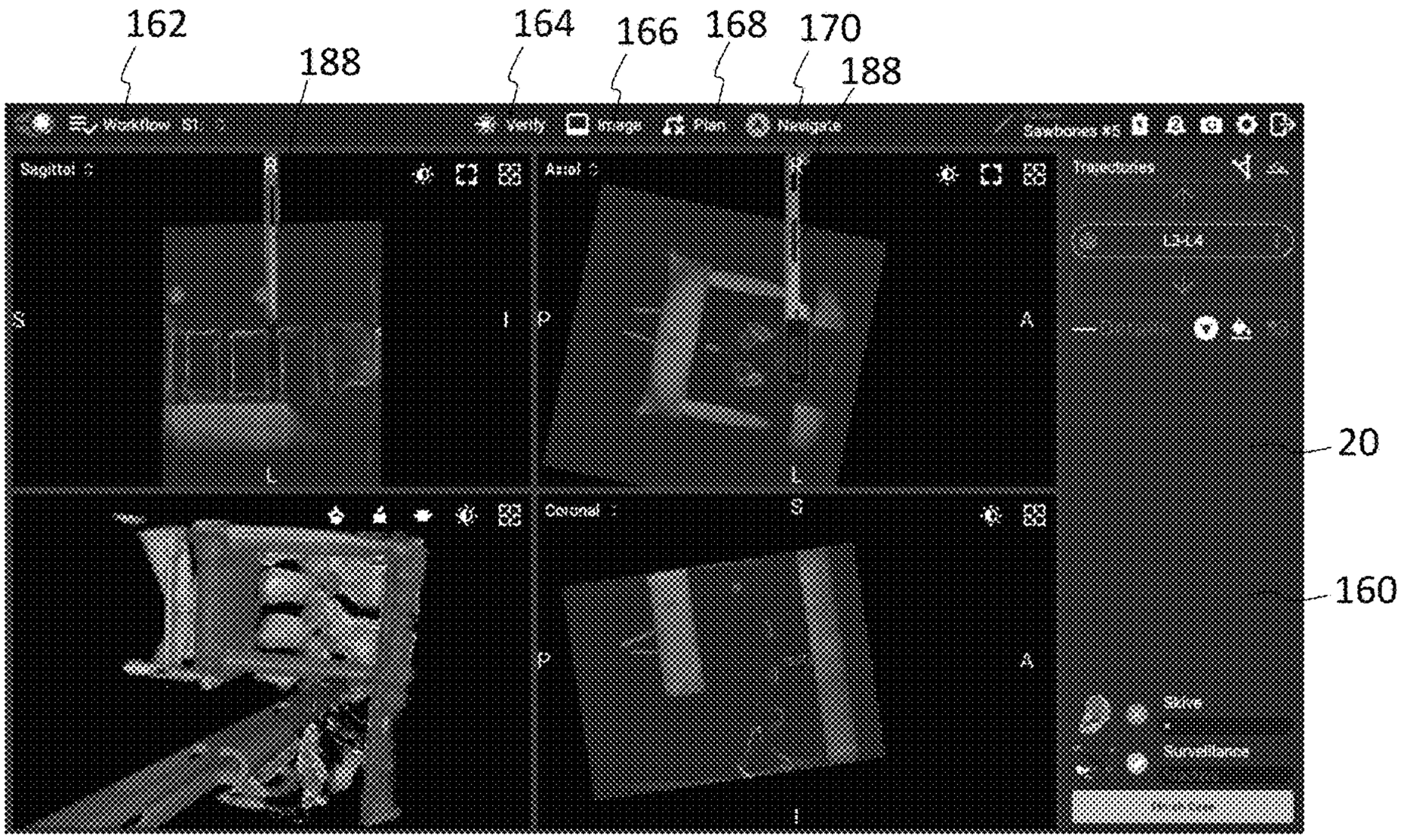

FIG. 20G

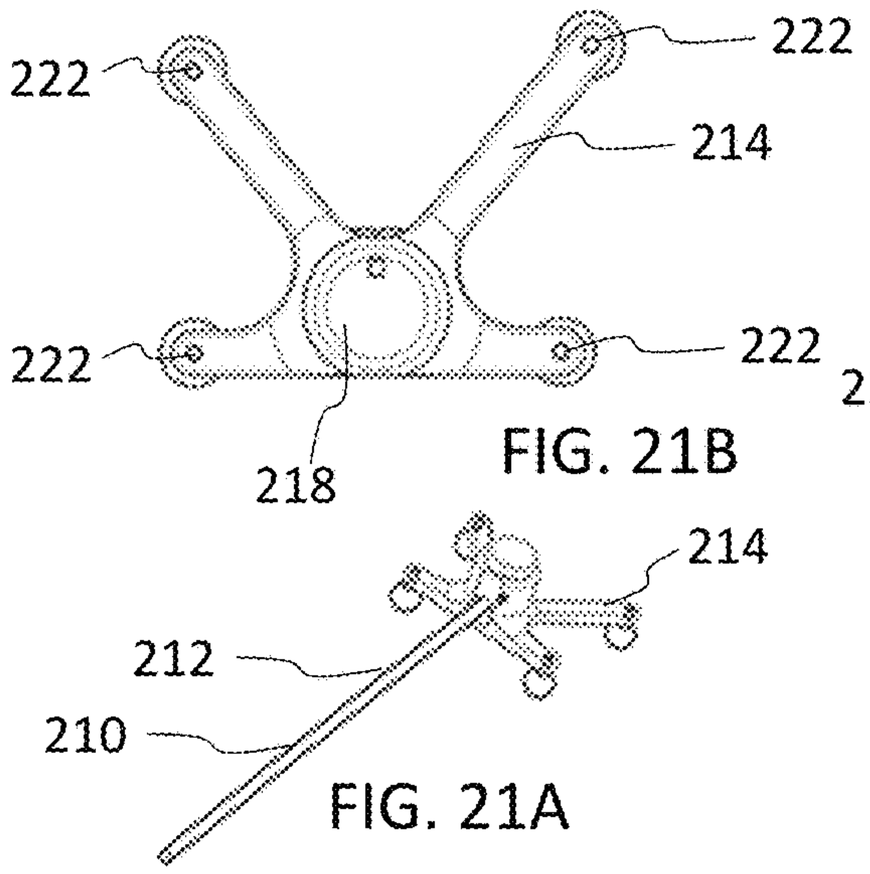

FIG. 21B

FIG. 21A

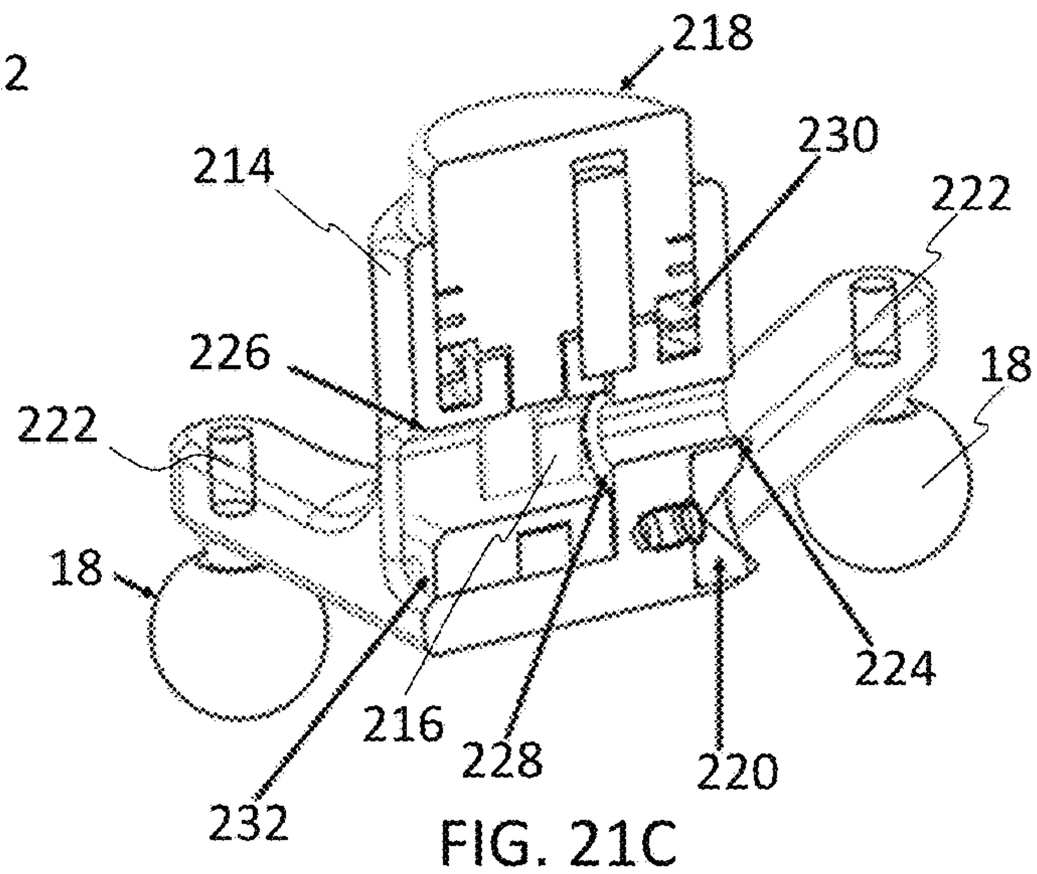

FIG. 21C

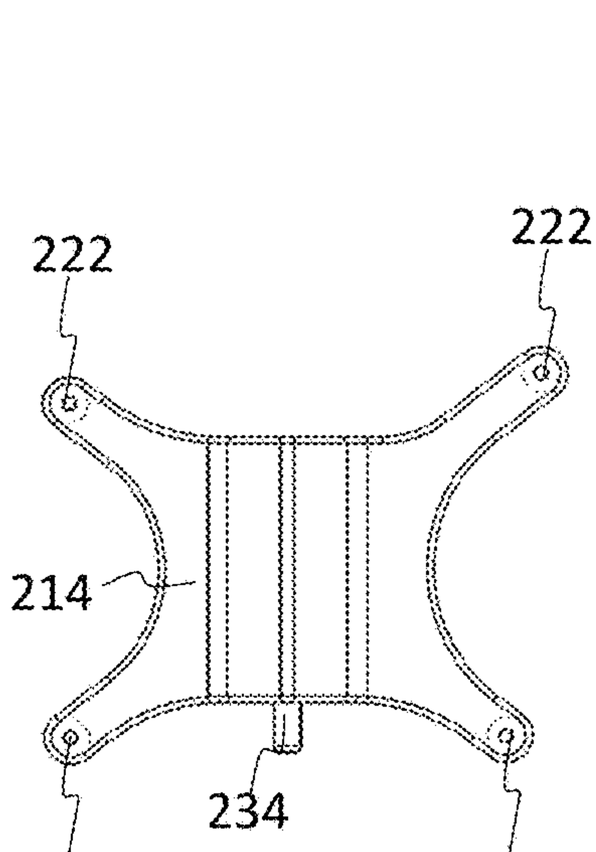

FIG. 21E

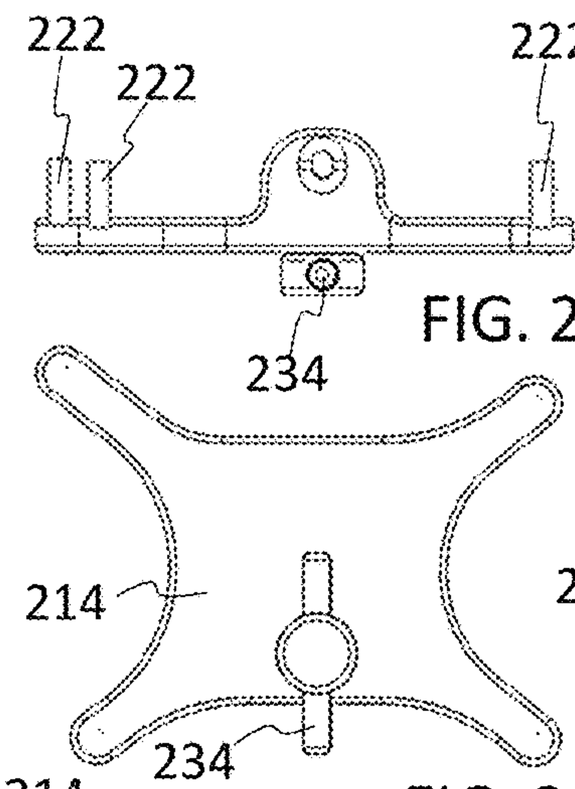

FIG. 21F

FIG. 21G

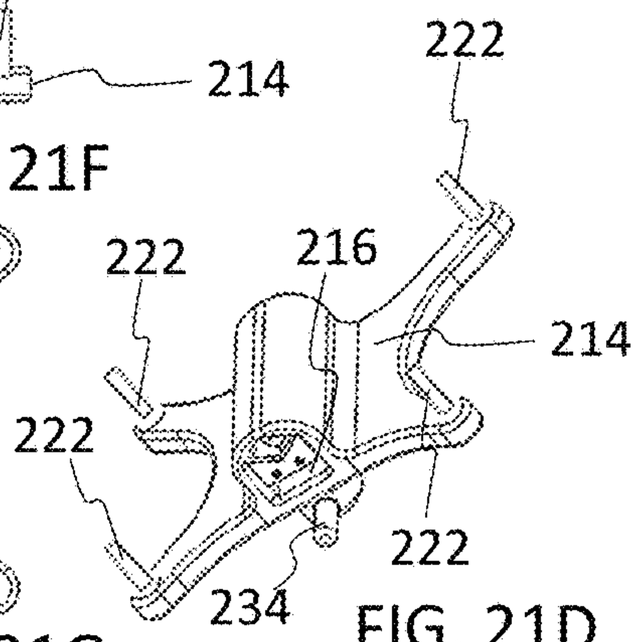

FIG. 21D

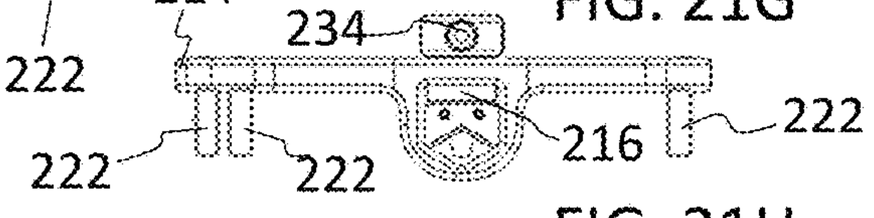

FIG. 21H

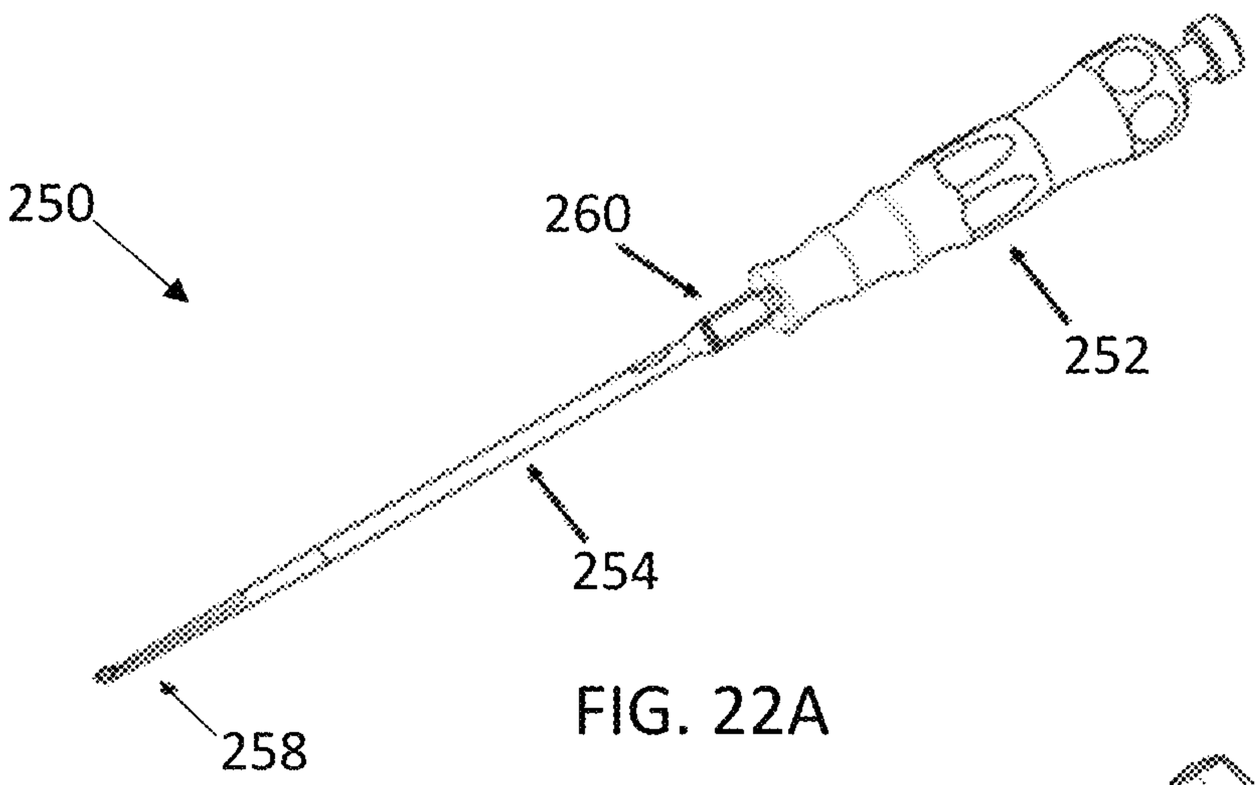

FIG. 22A

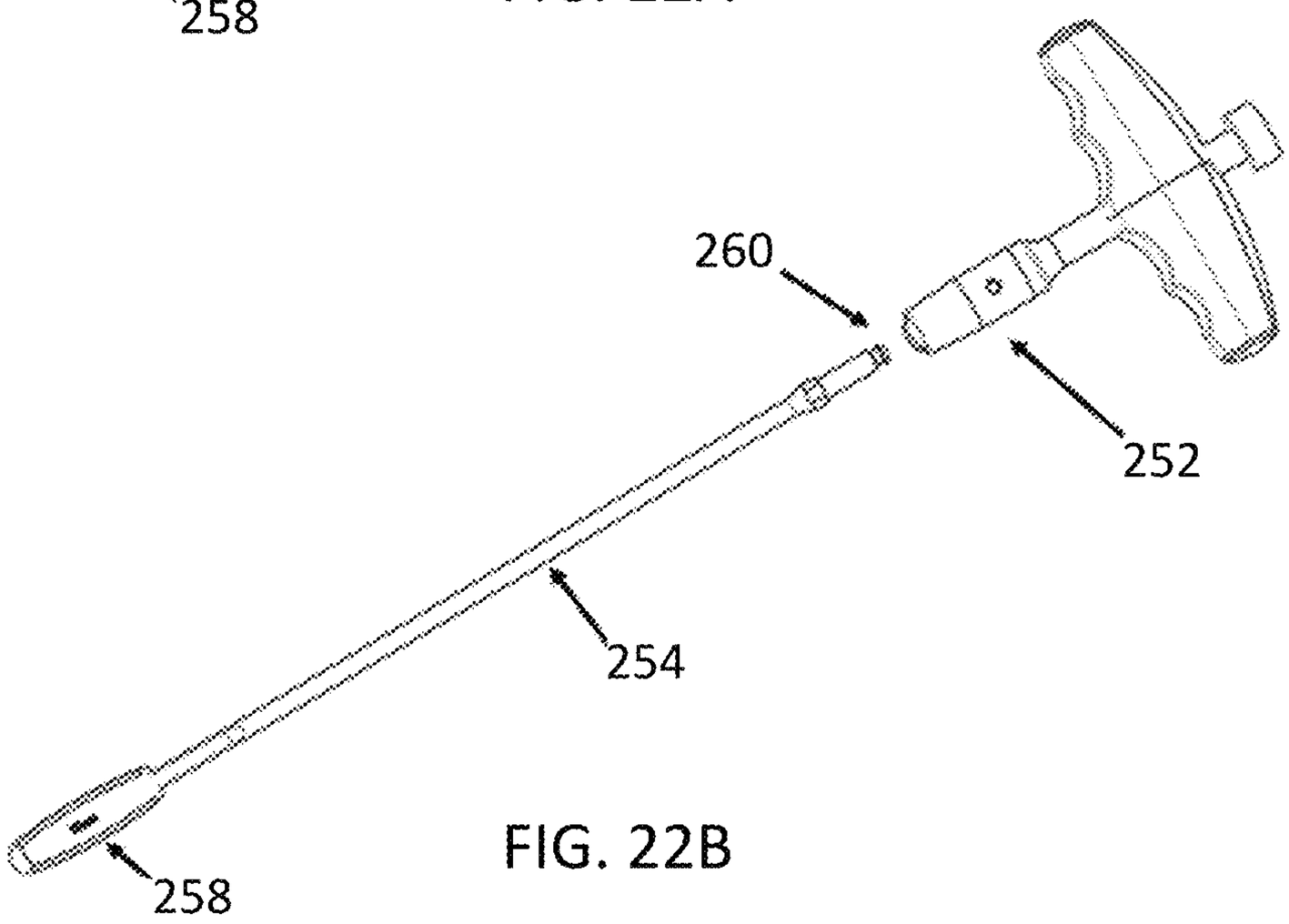

FIG. 22B

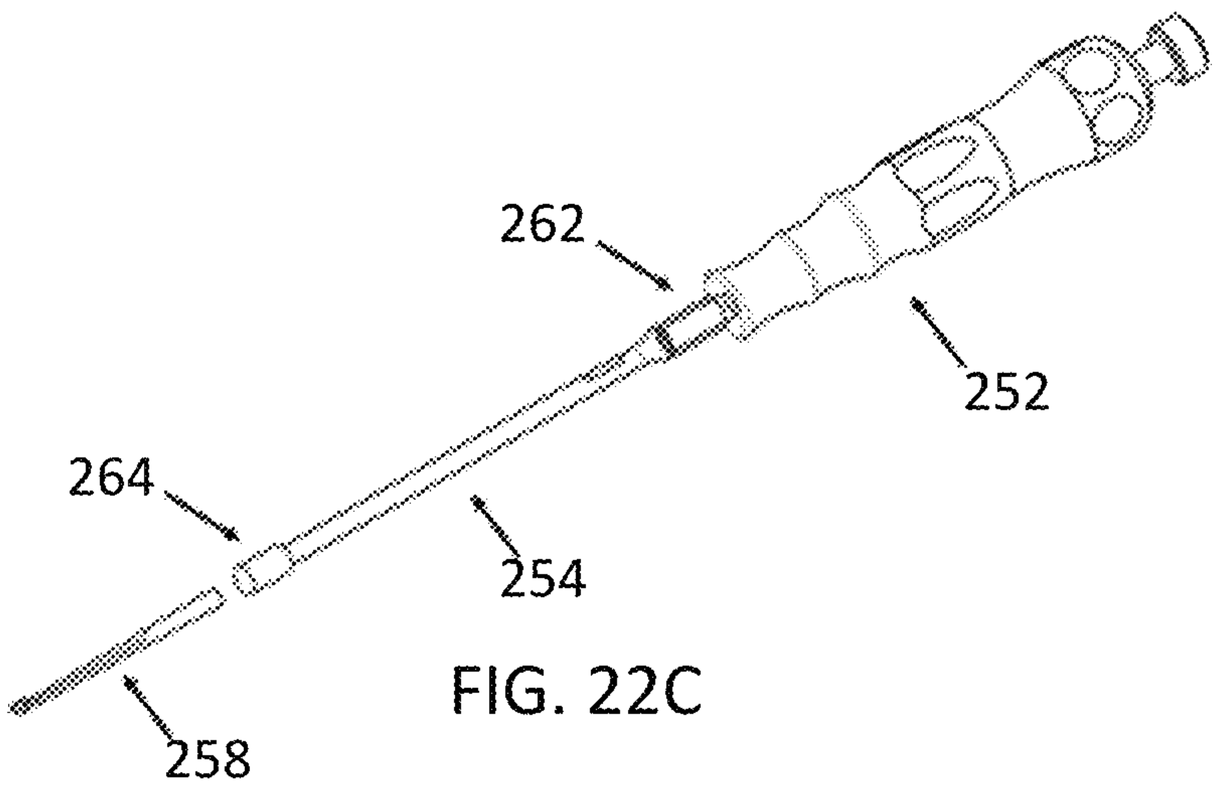

FIG. 22C

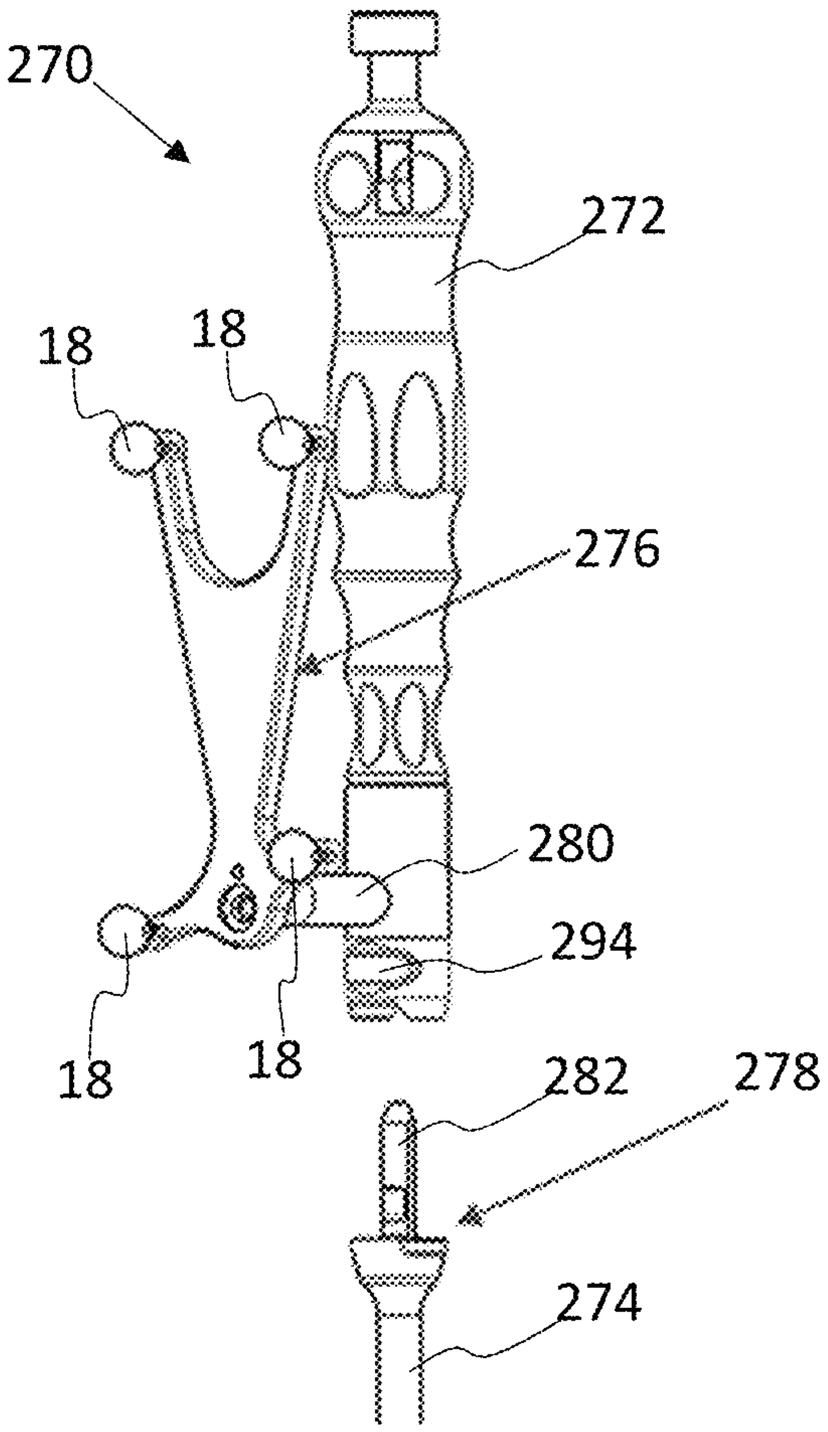

FIG. 23A

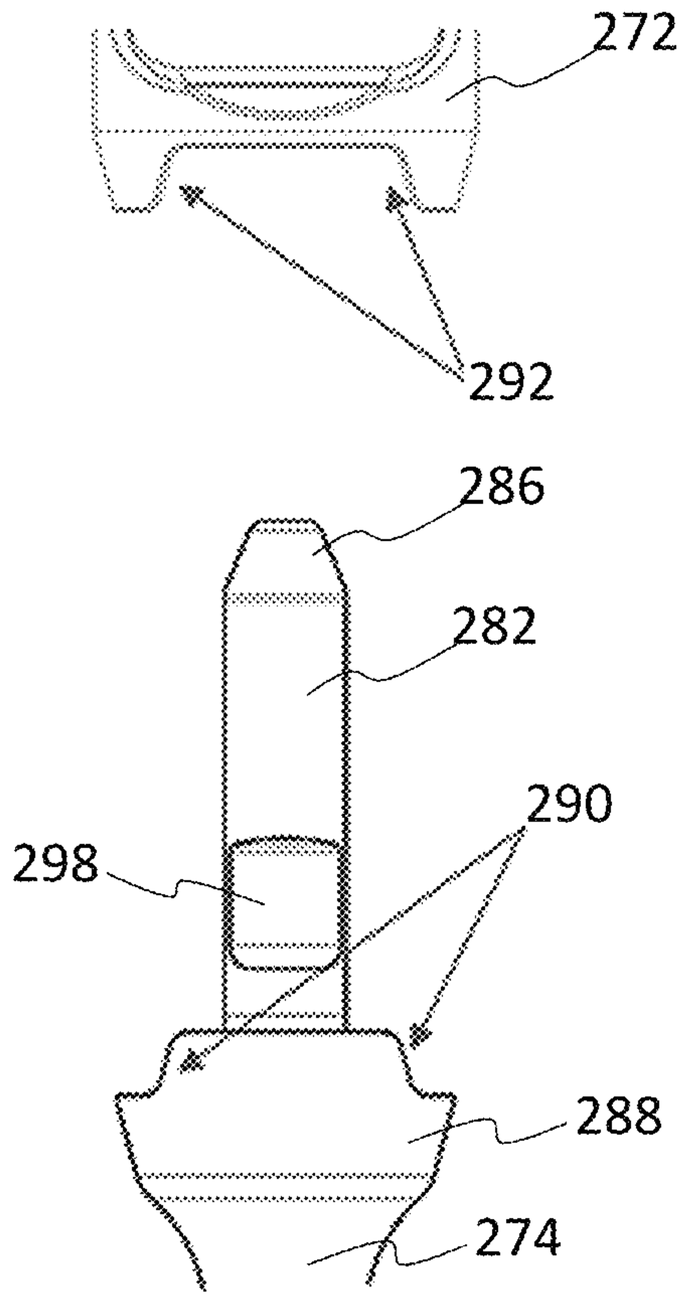

FIG. 23B

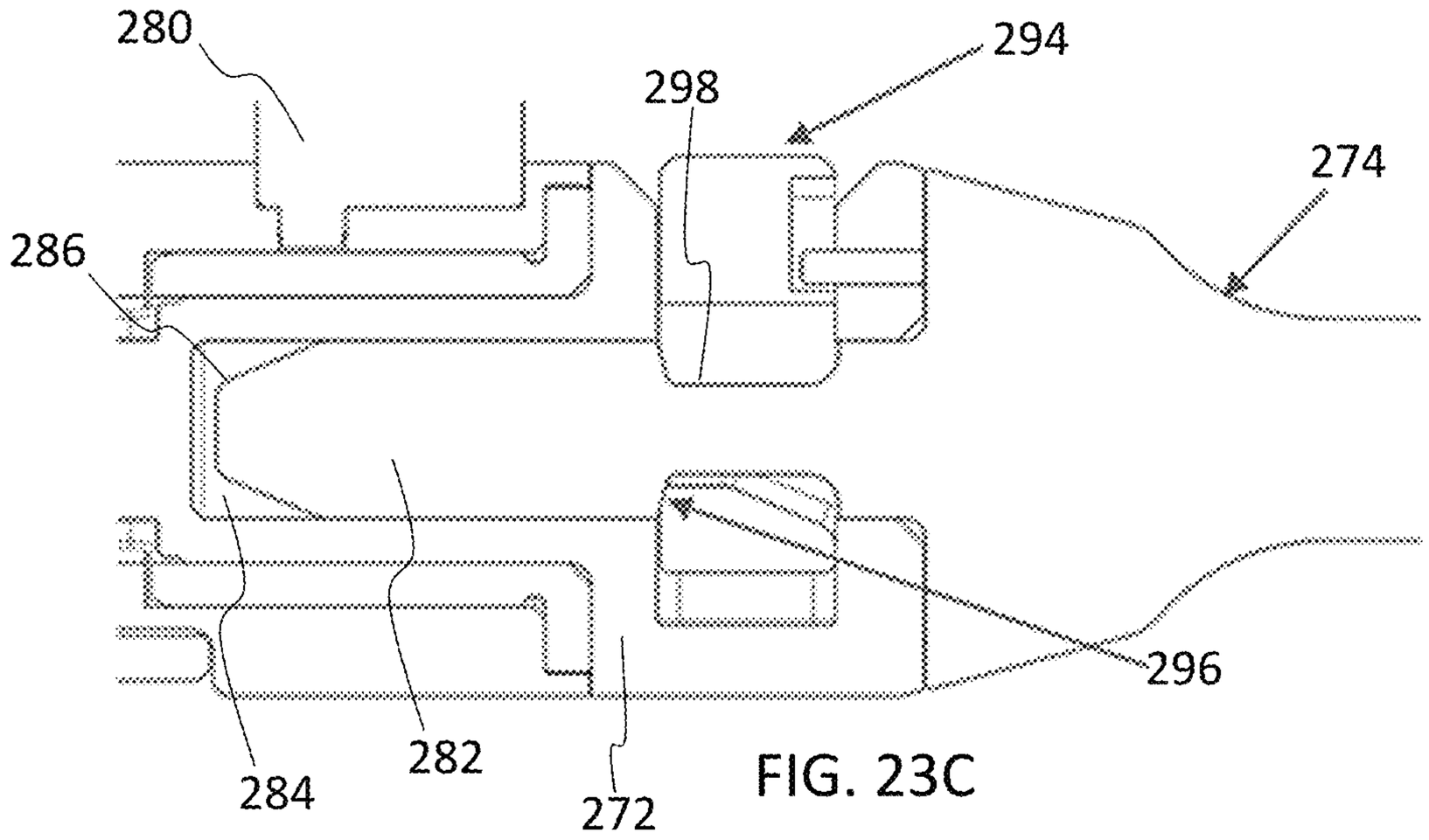

FIG. 23C

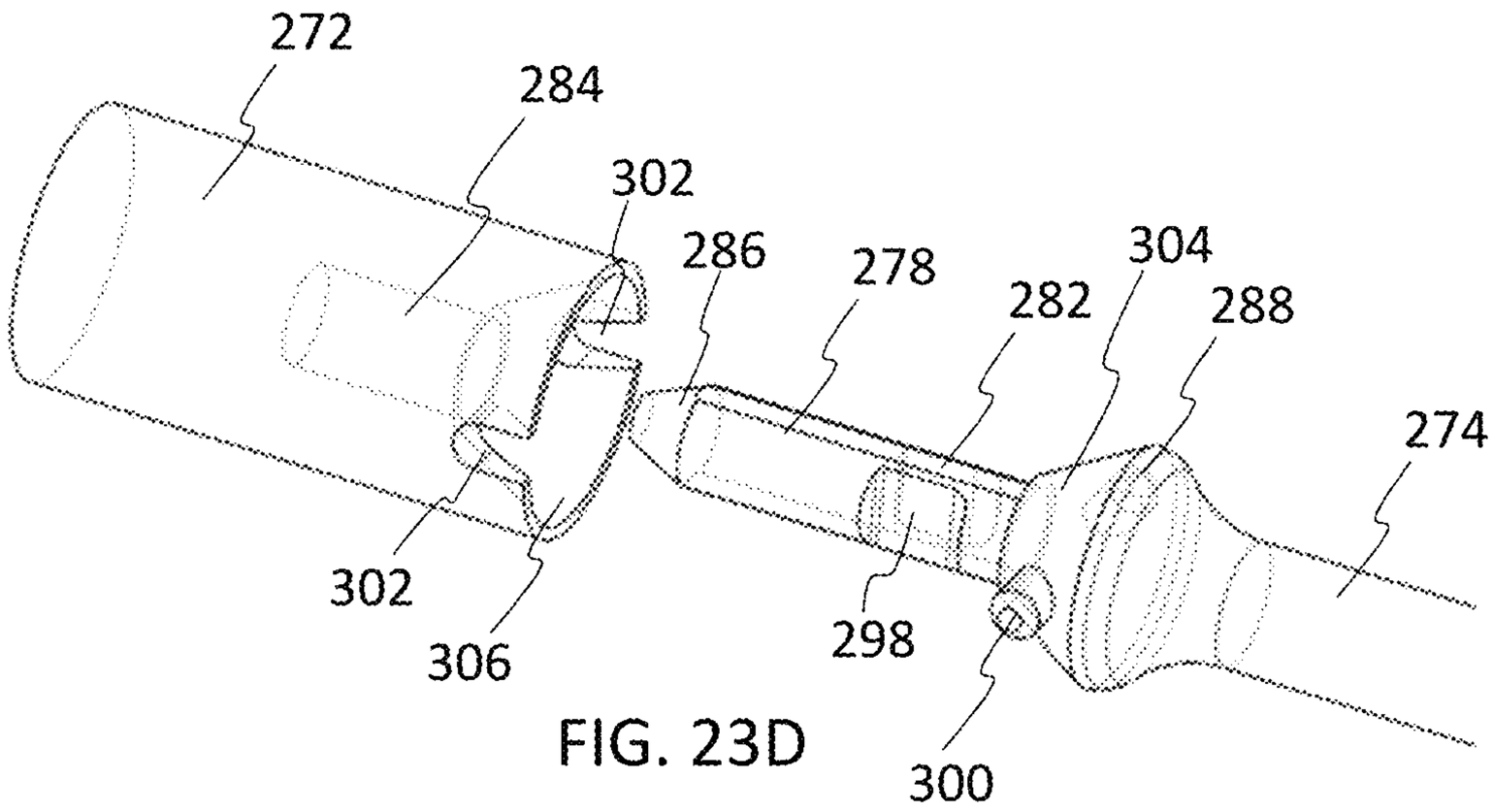

FIG. 23D

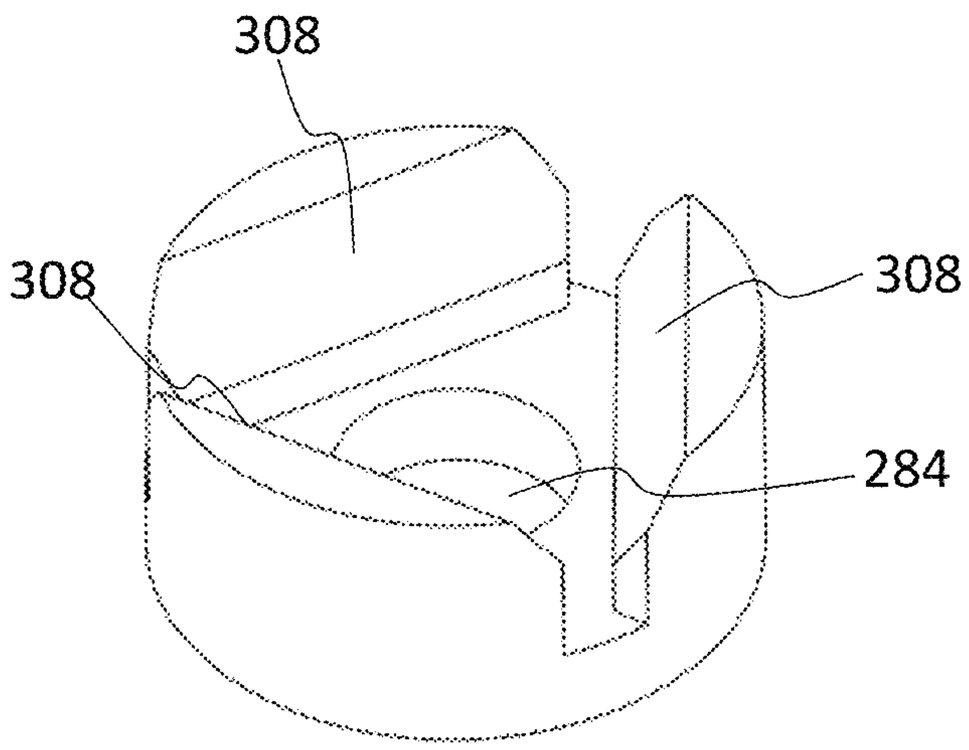

FIG. 23E

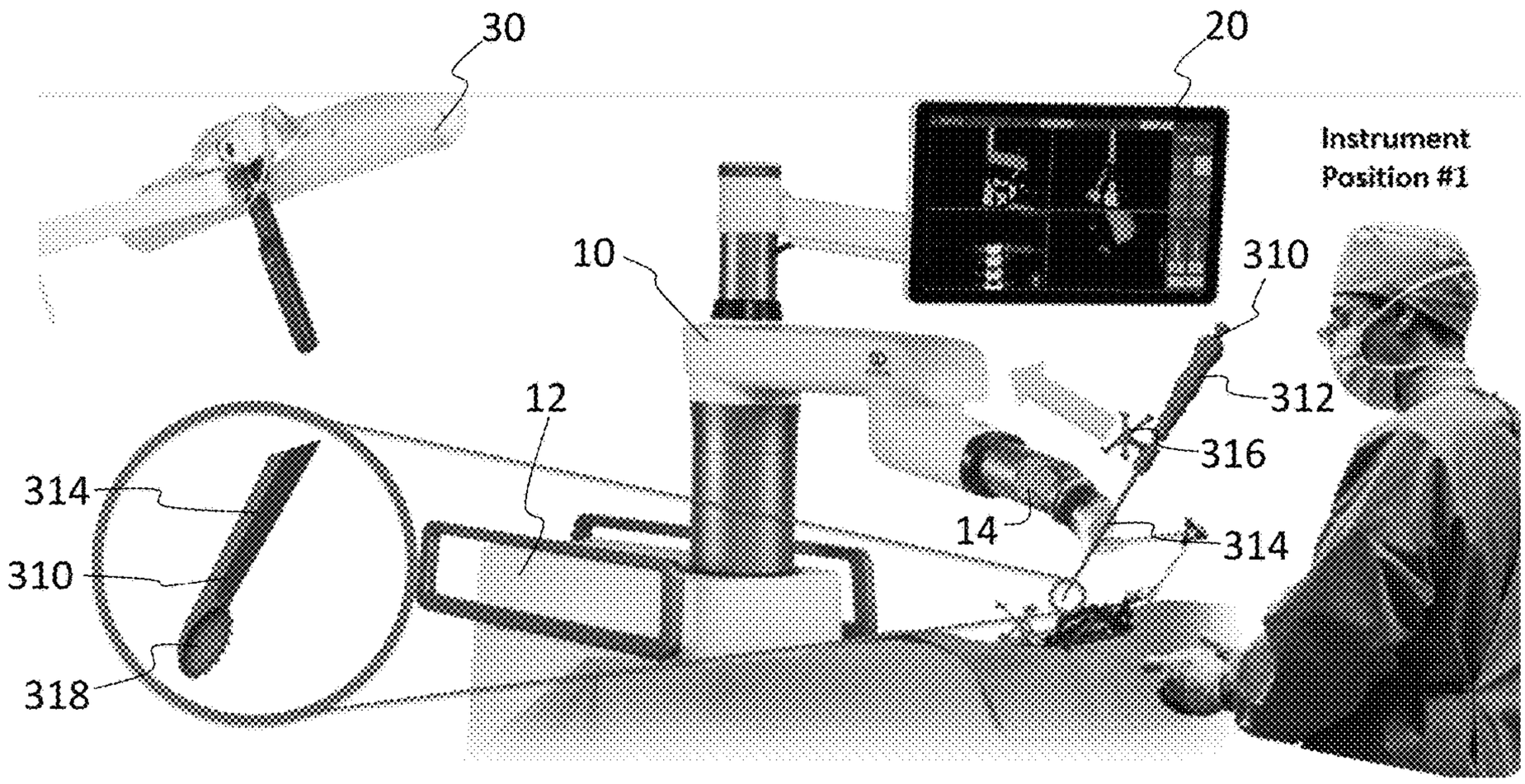

FIG. 24A

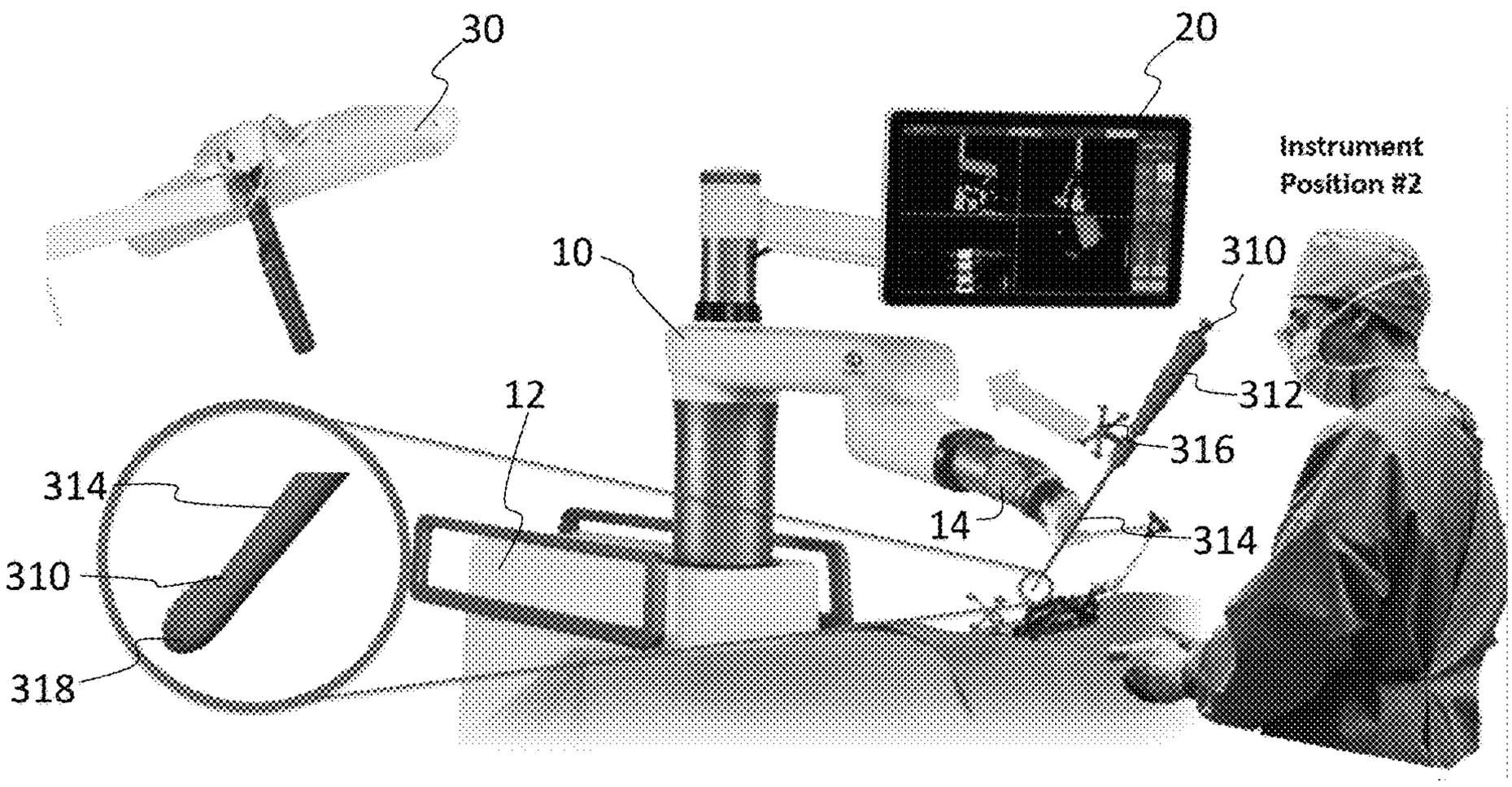

FIG. 24B

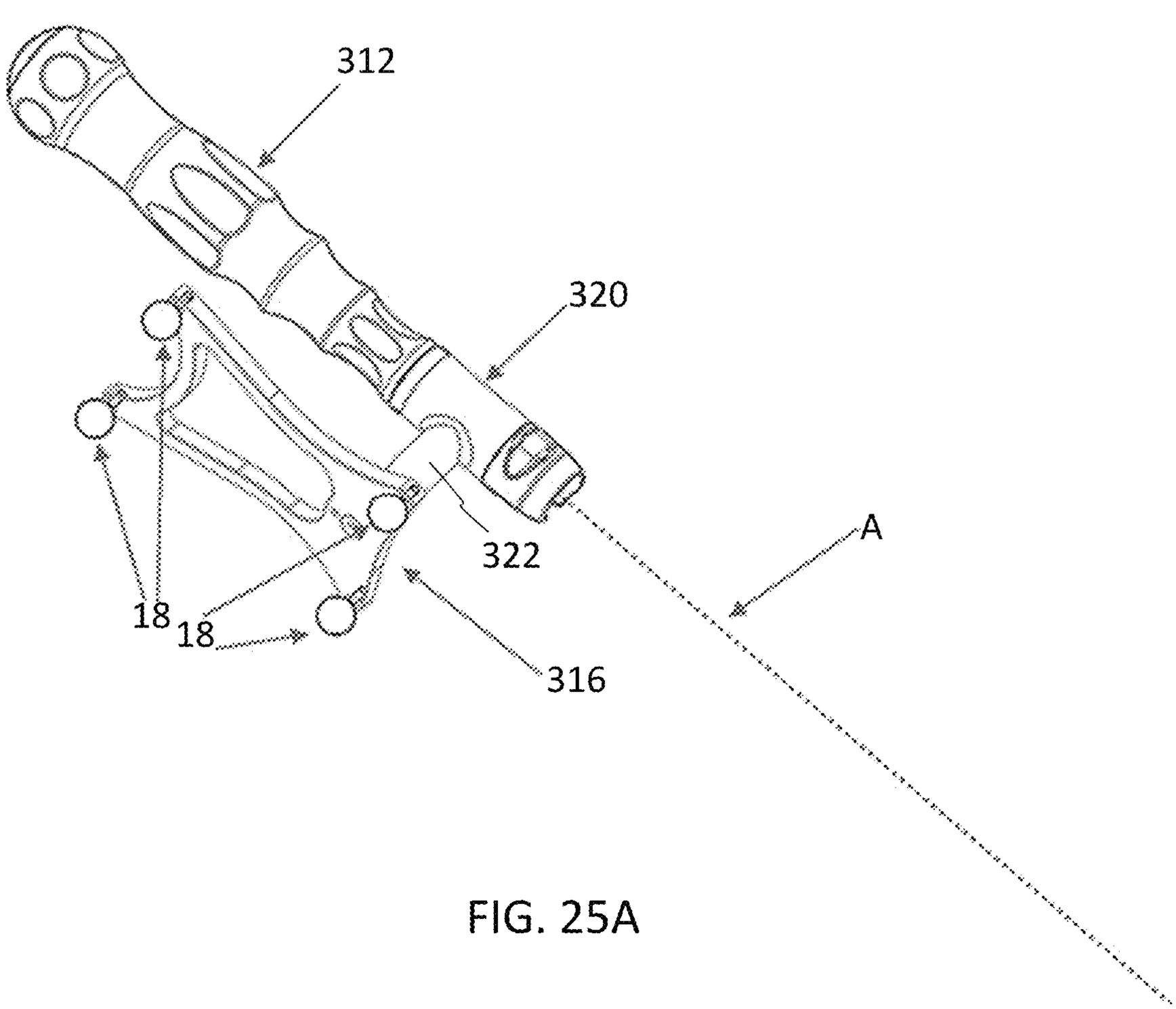

FIG. 25A

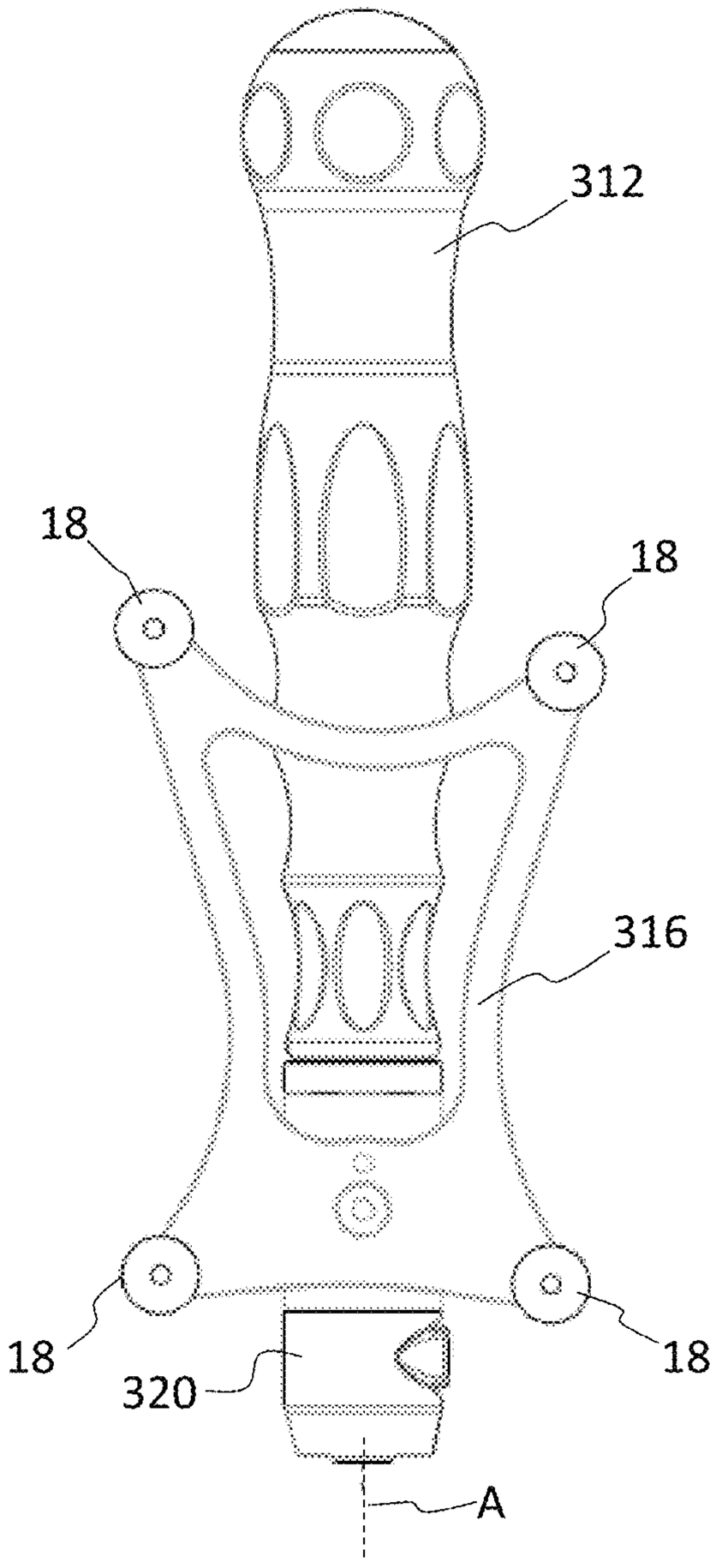

FIG. 25B

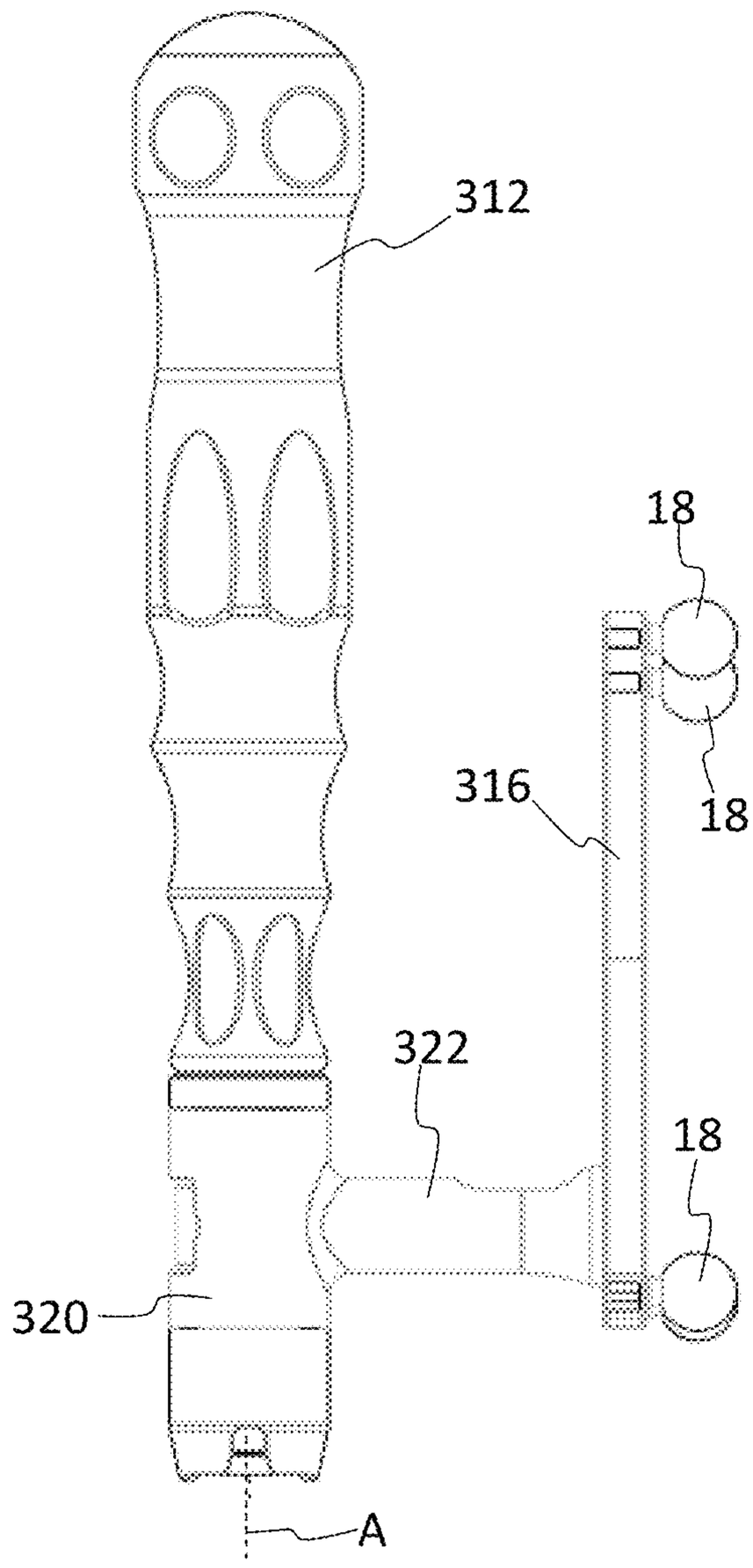

FIG. 25C

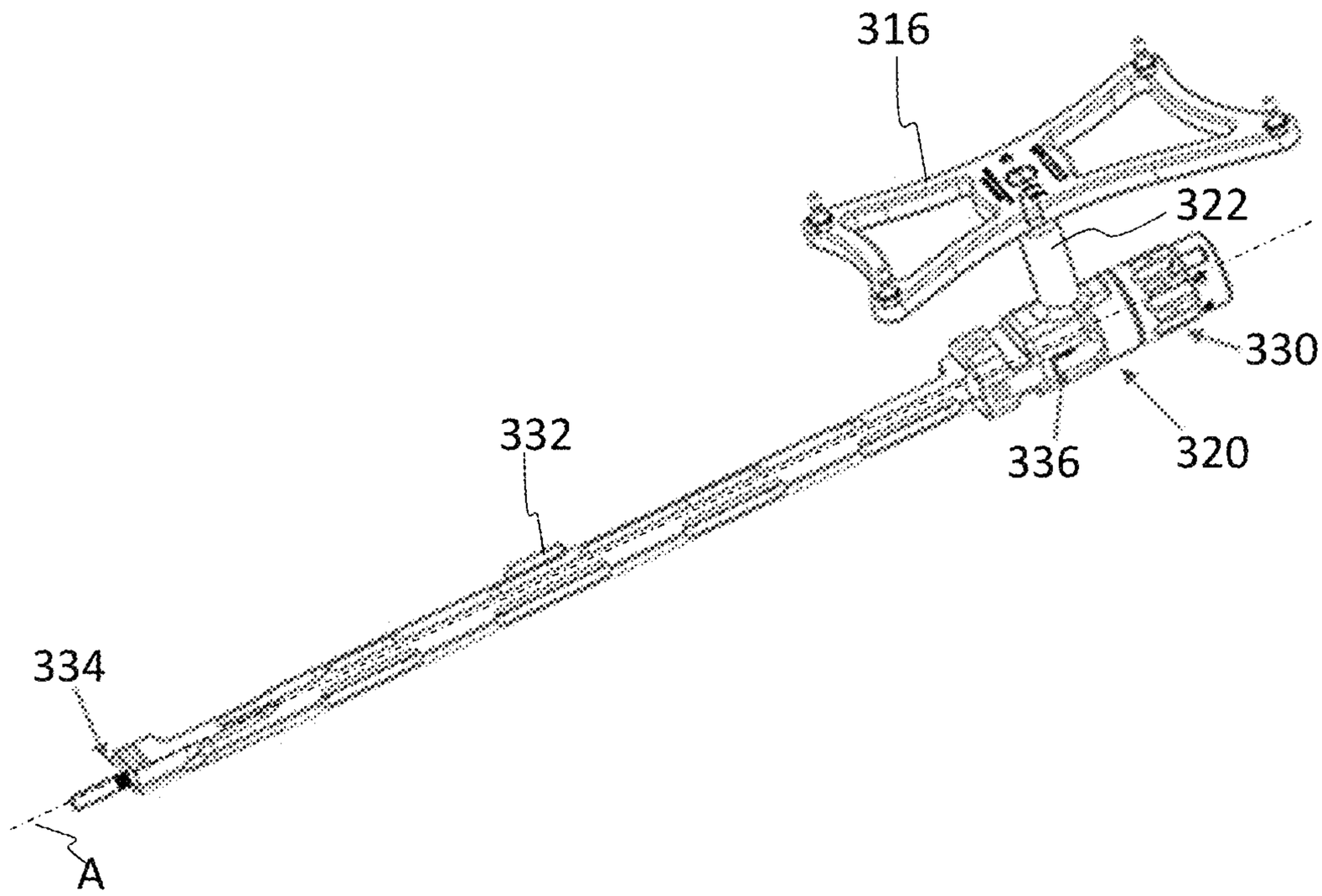

FIG. 26A

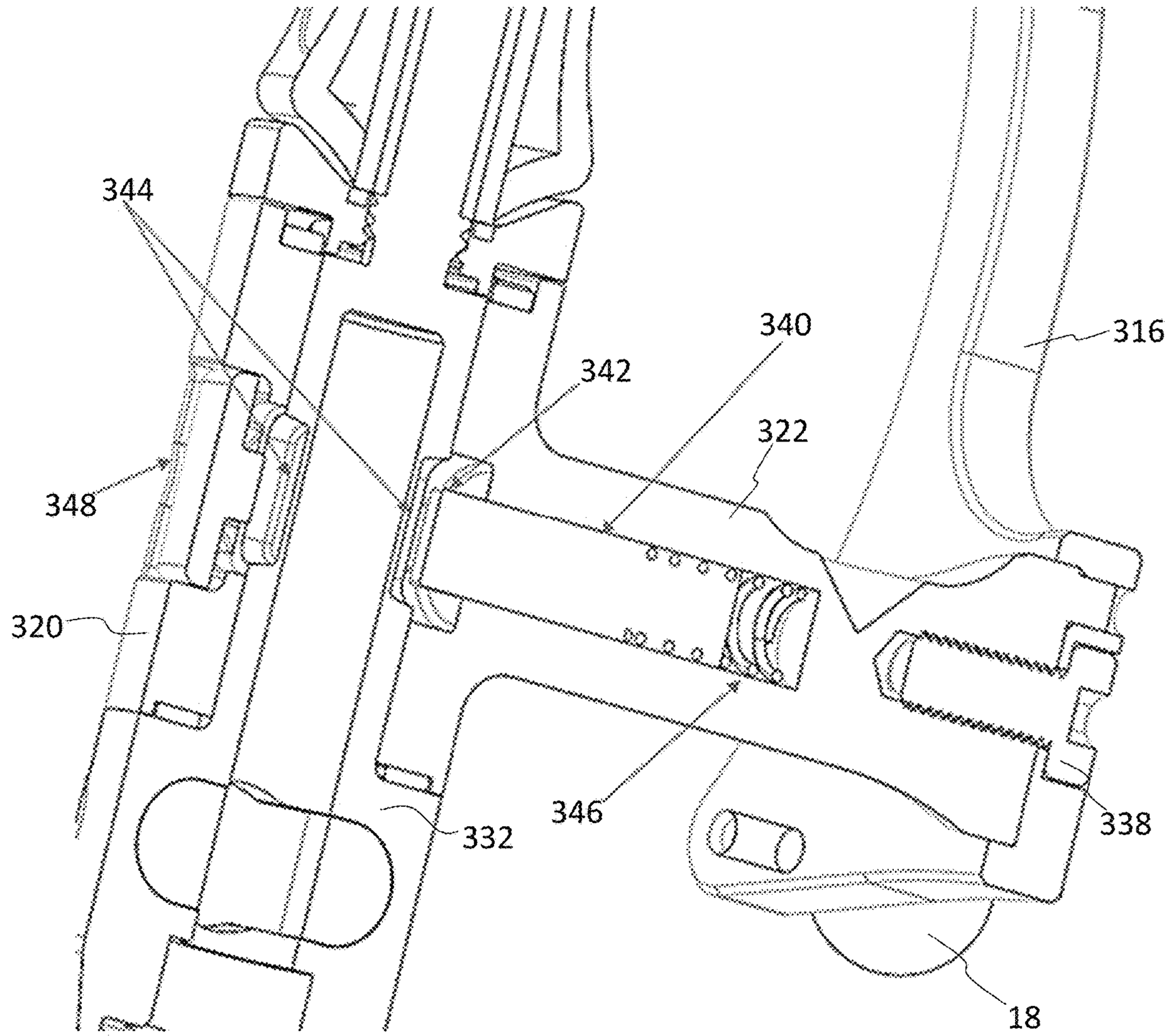

FIG. 26B

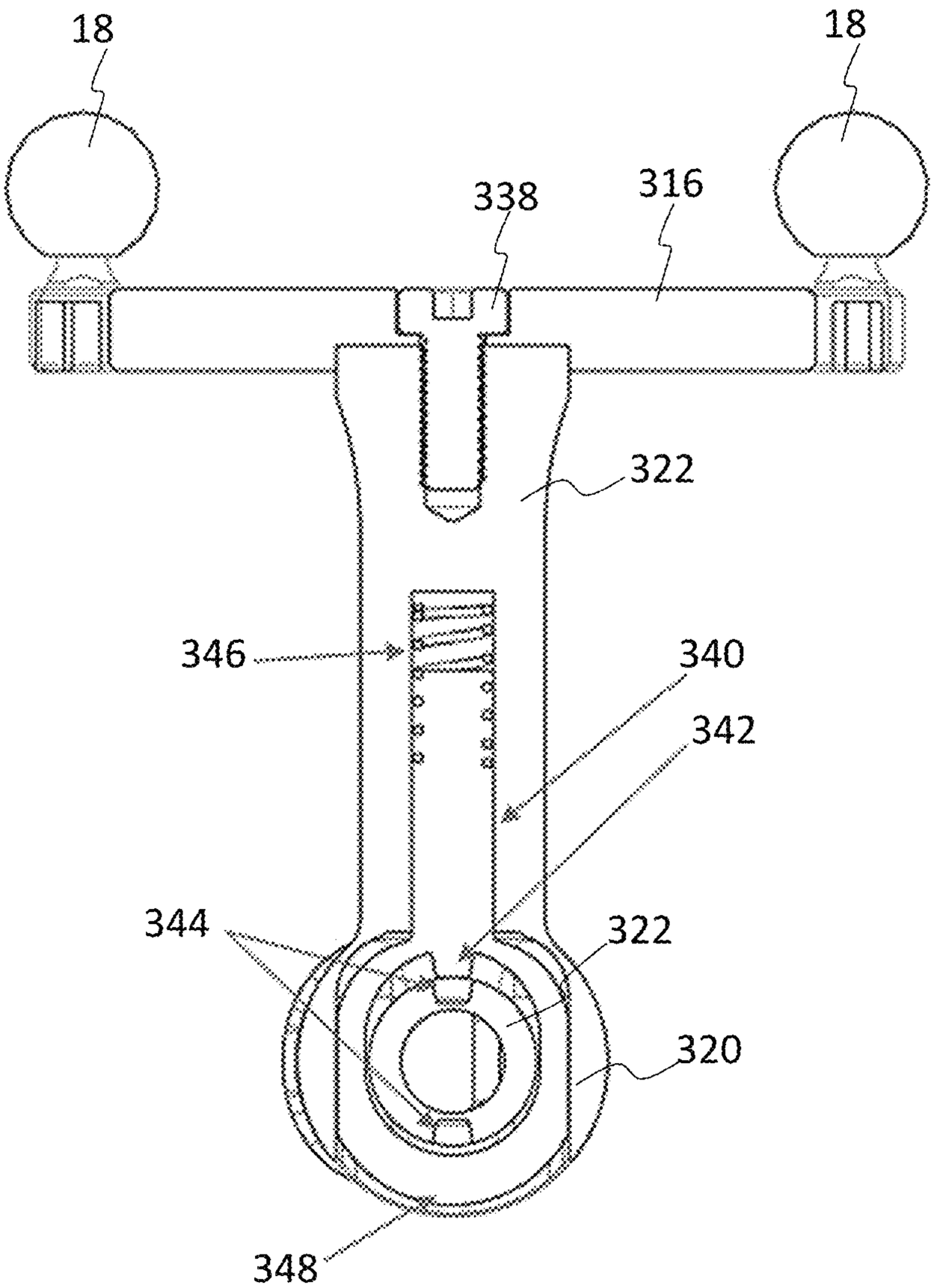

FIG. 26C

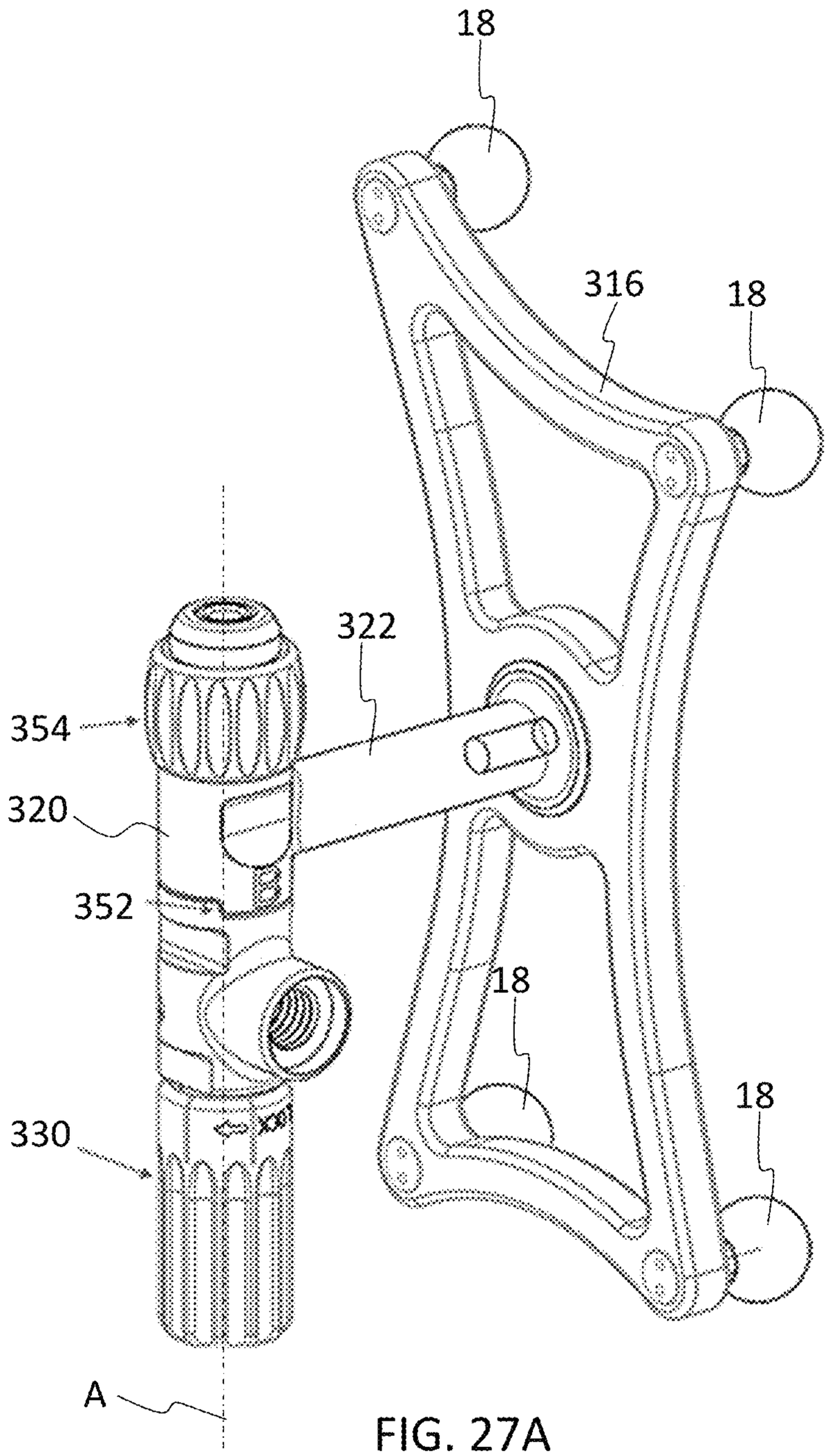

FIG. 27A

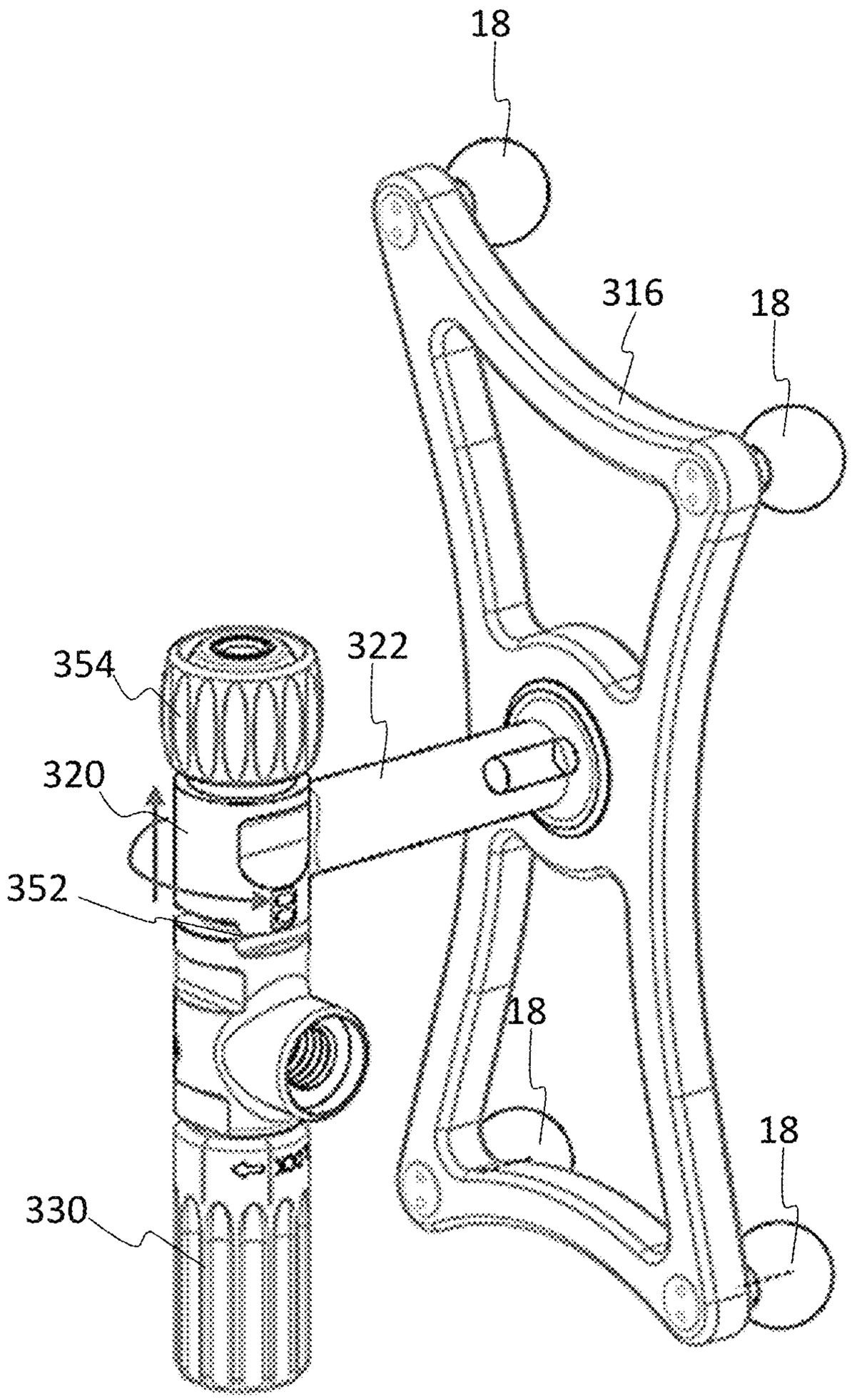

FIG. 27B

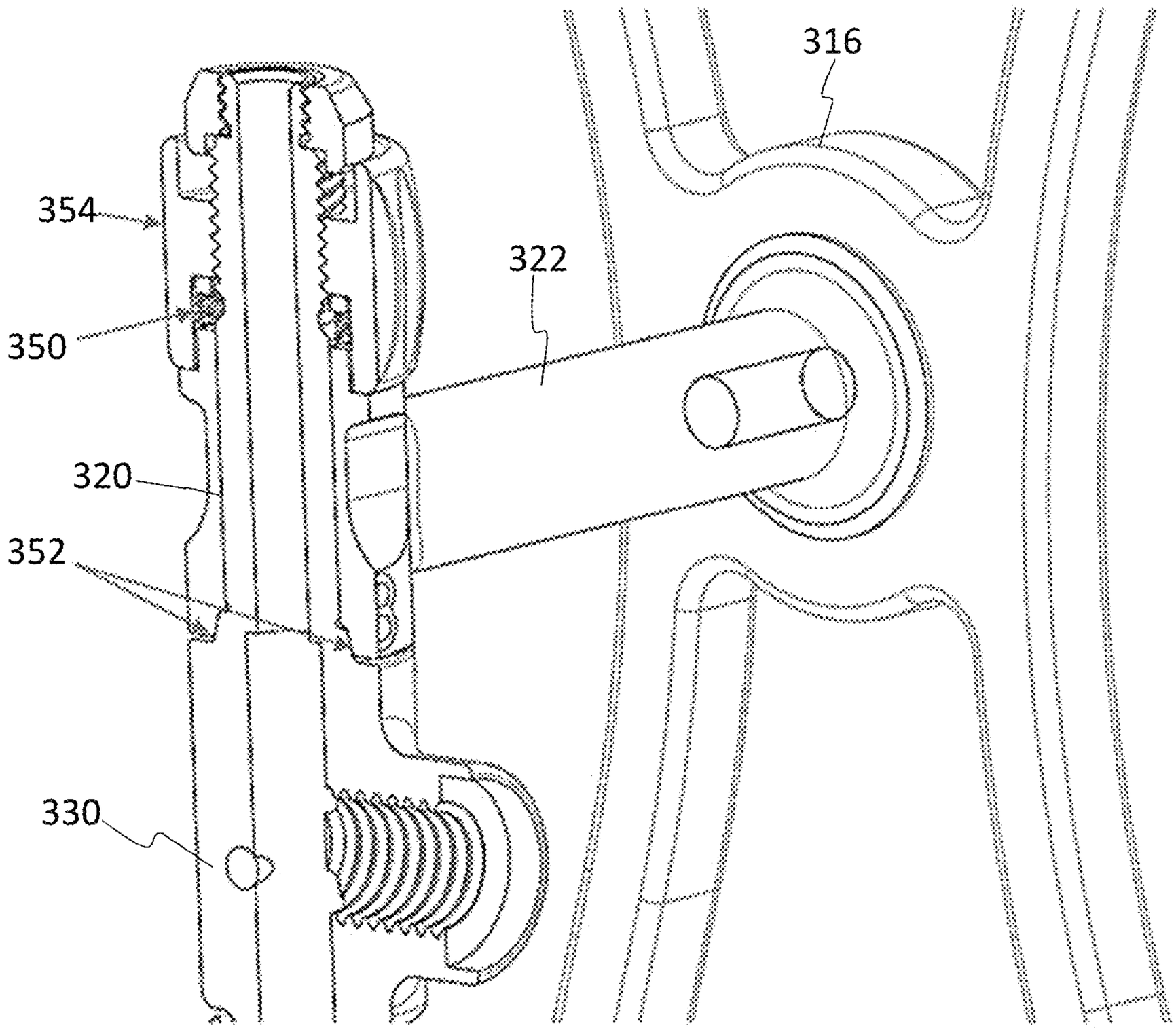

FIG. 27C

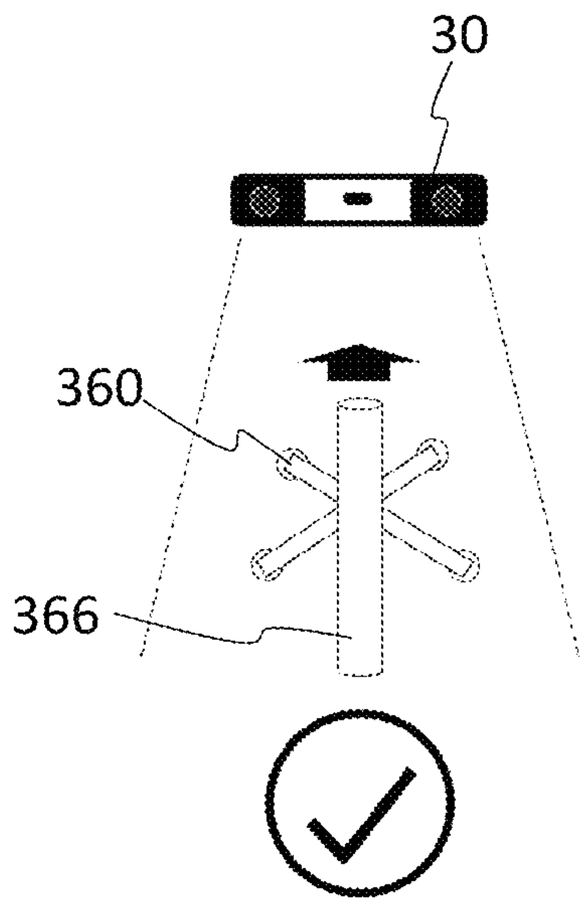

FIG. 28A

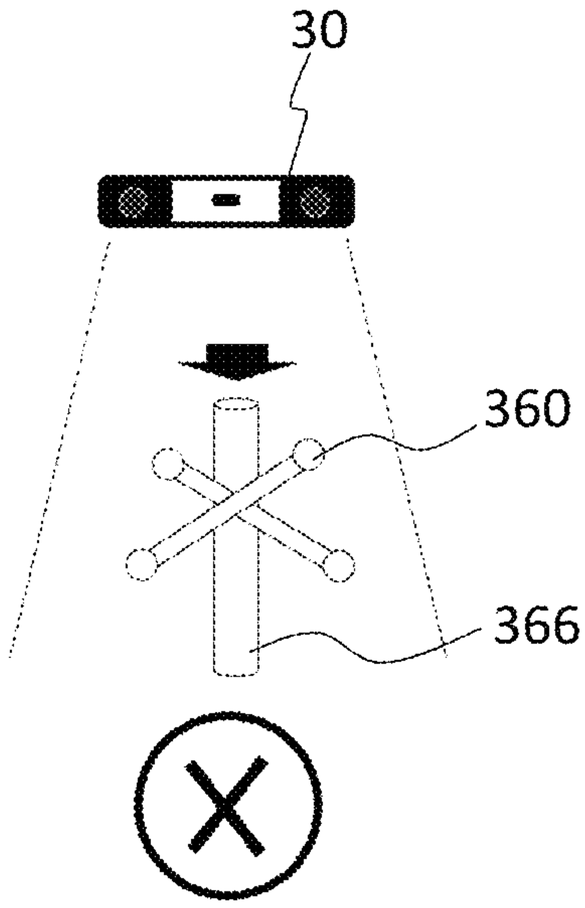

FIG. 28B

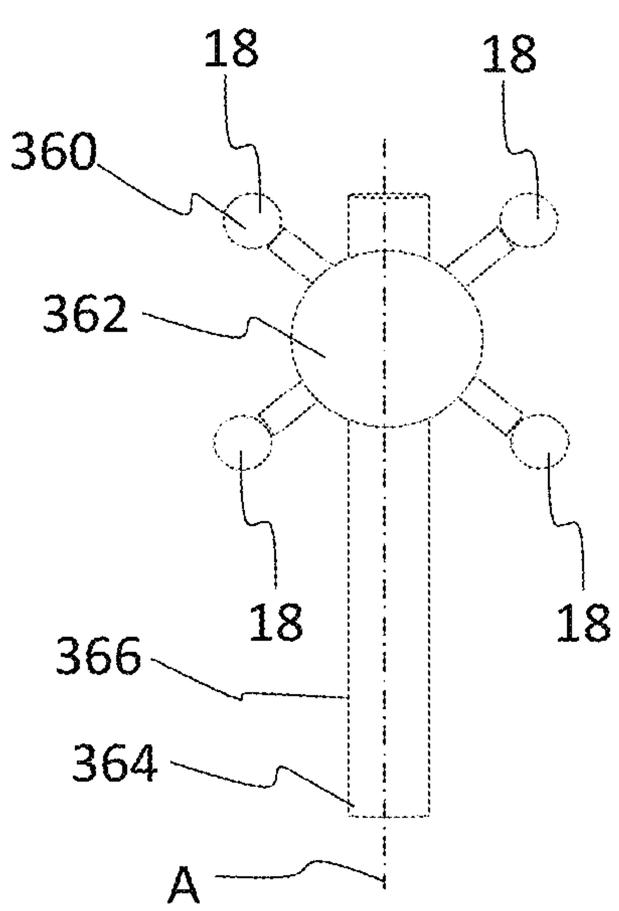

FIG. 28C

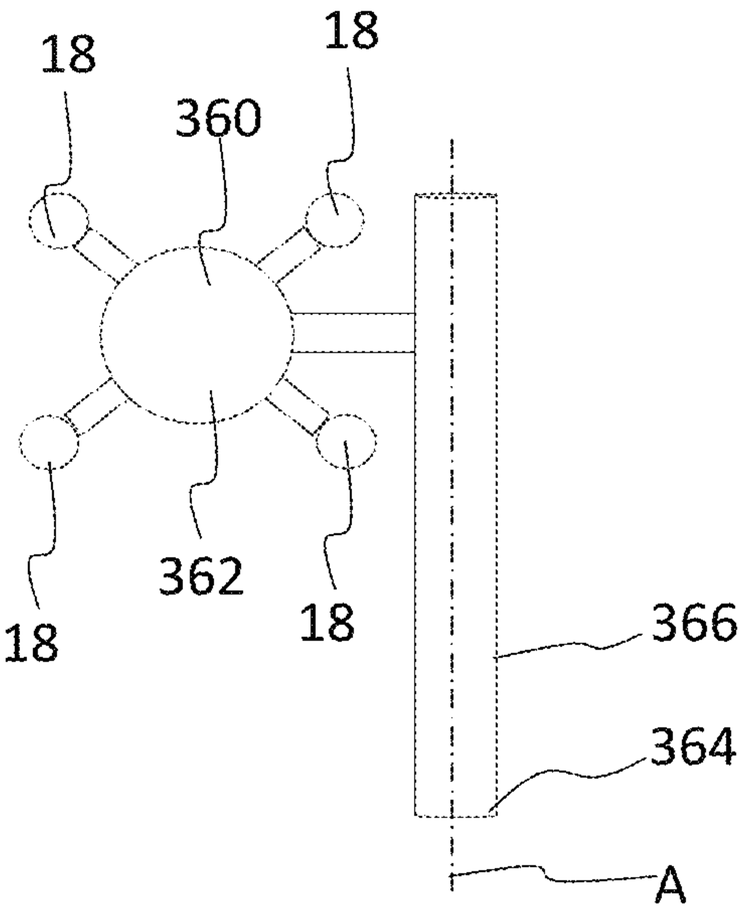

FIG. 28D

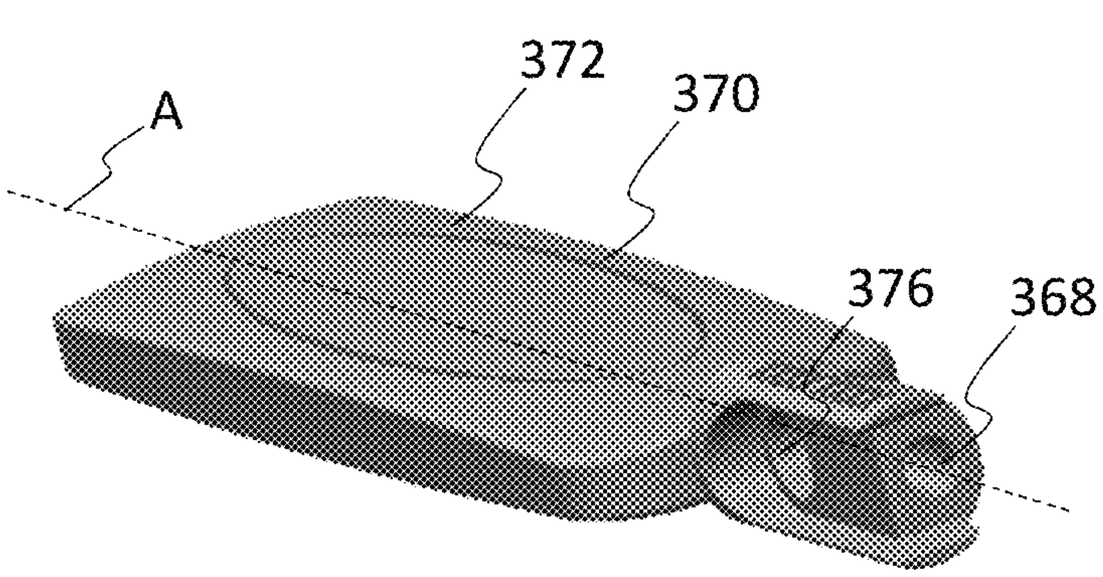

FIG. 29A

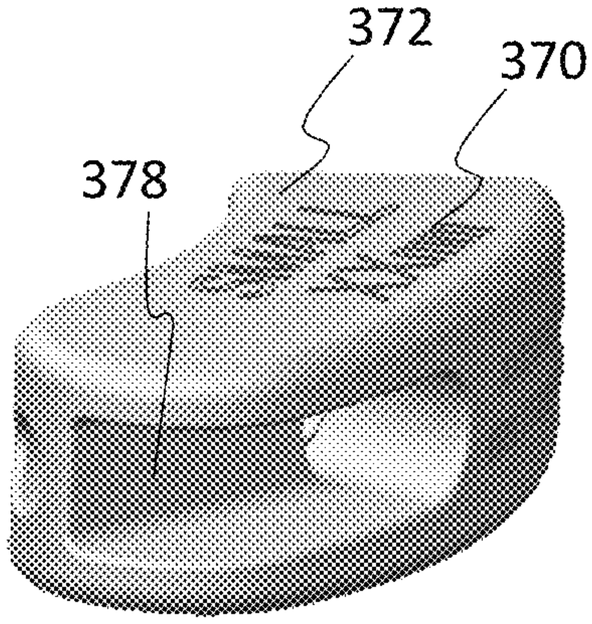

FIG. 29B

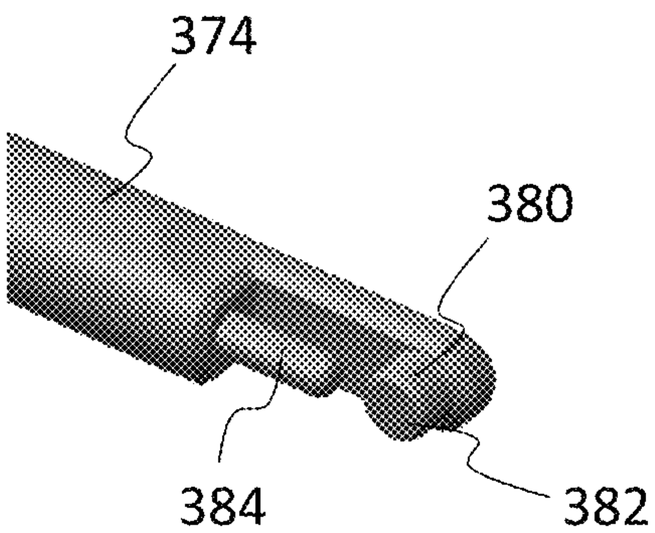

FIG. 29C

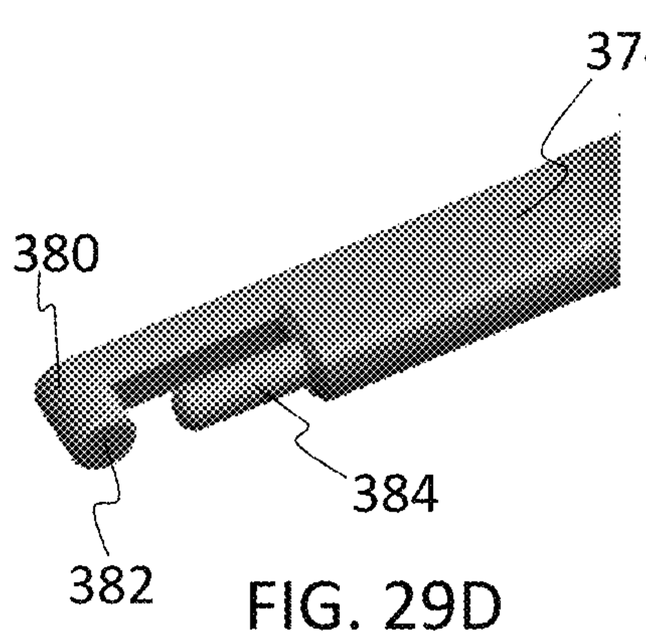

FIG. 29D

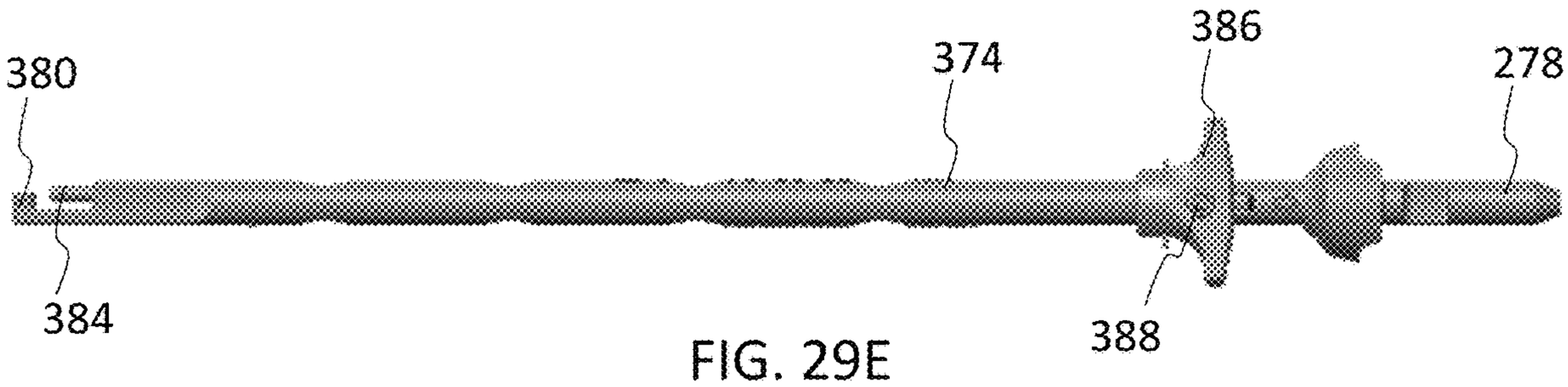

FIG. 29E

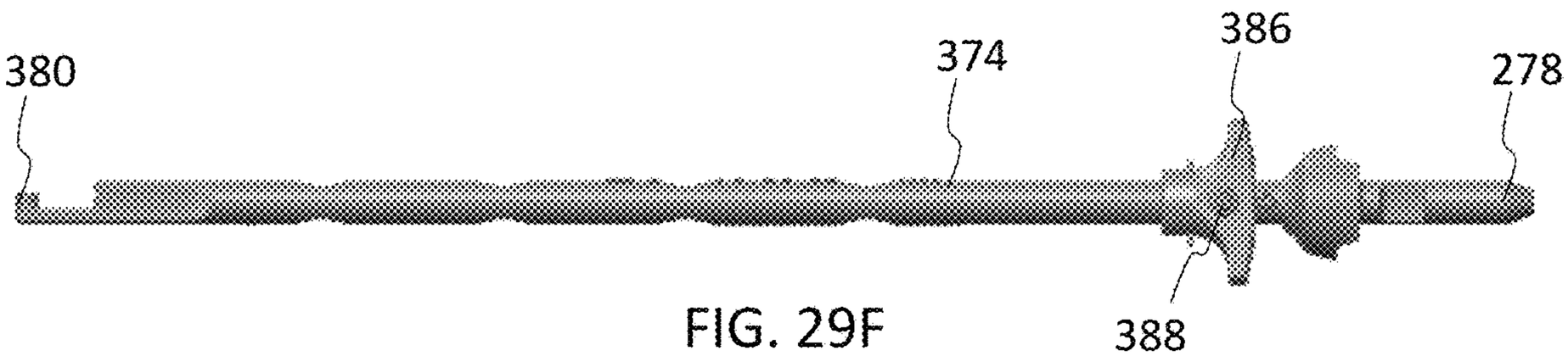

FIG. 29F

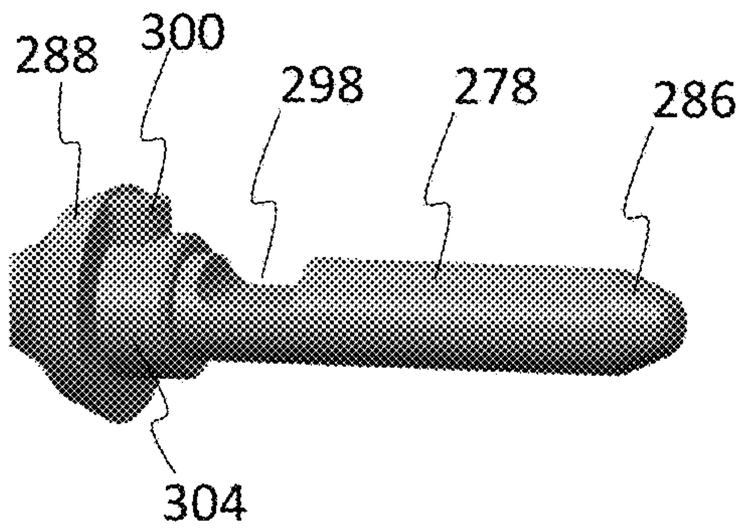

FIG. 29G

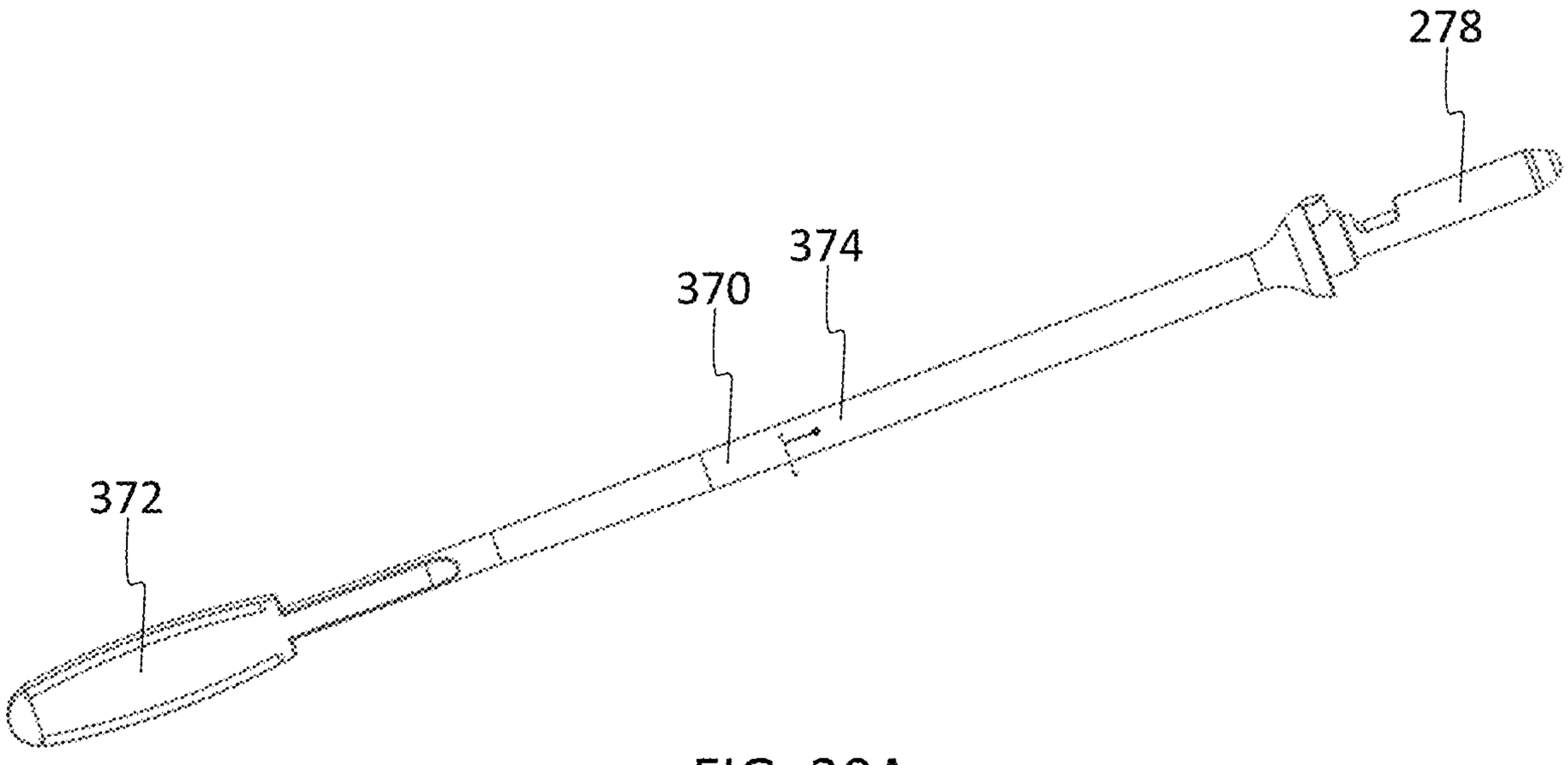

FIG. 30A

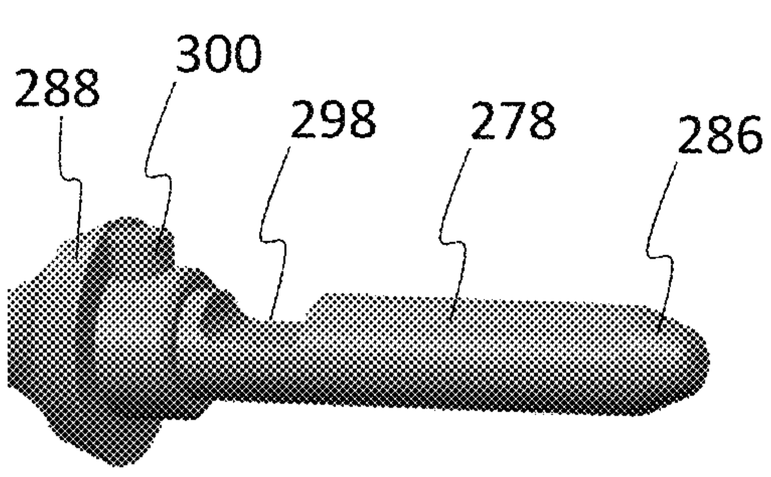

FIG. 30B

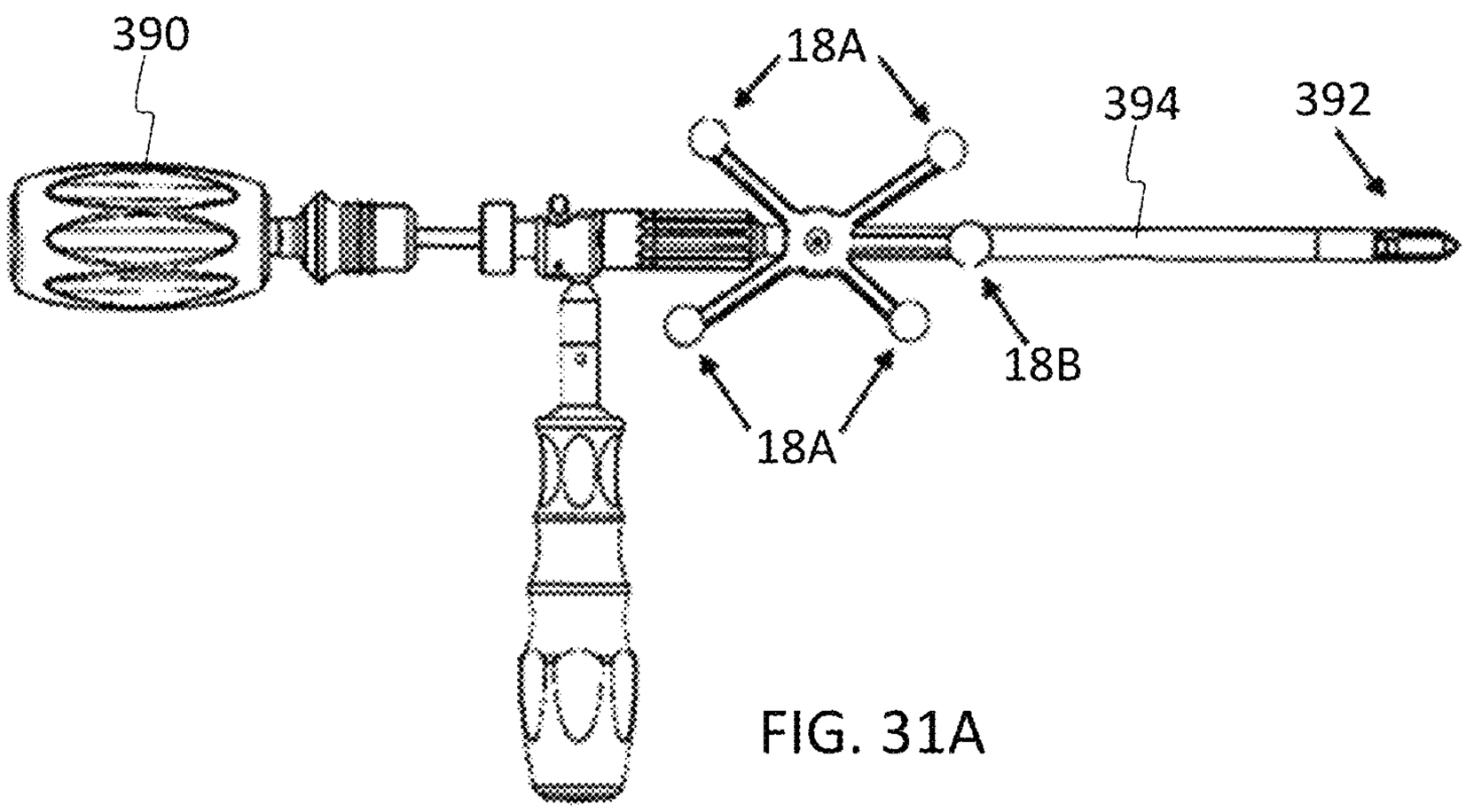

FIG. 31A

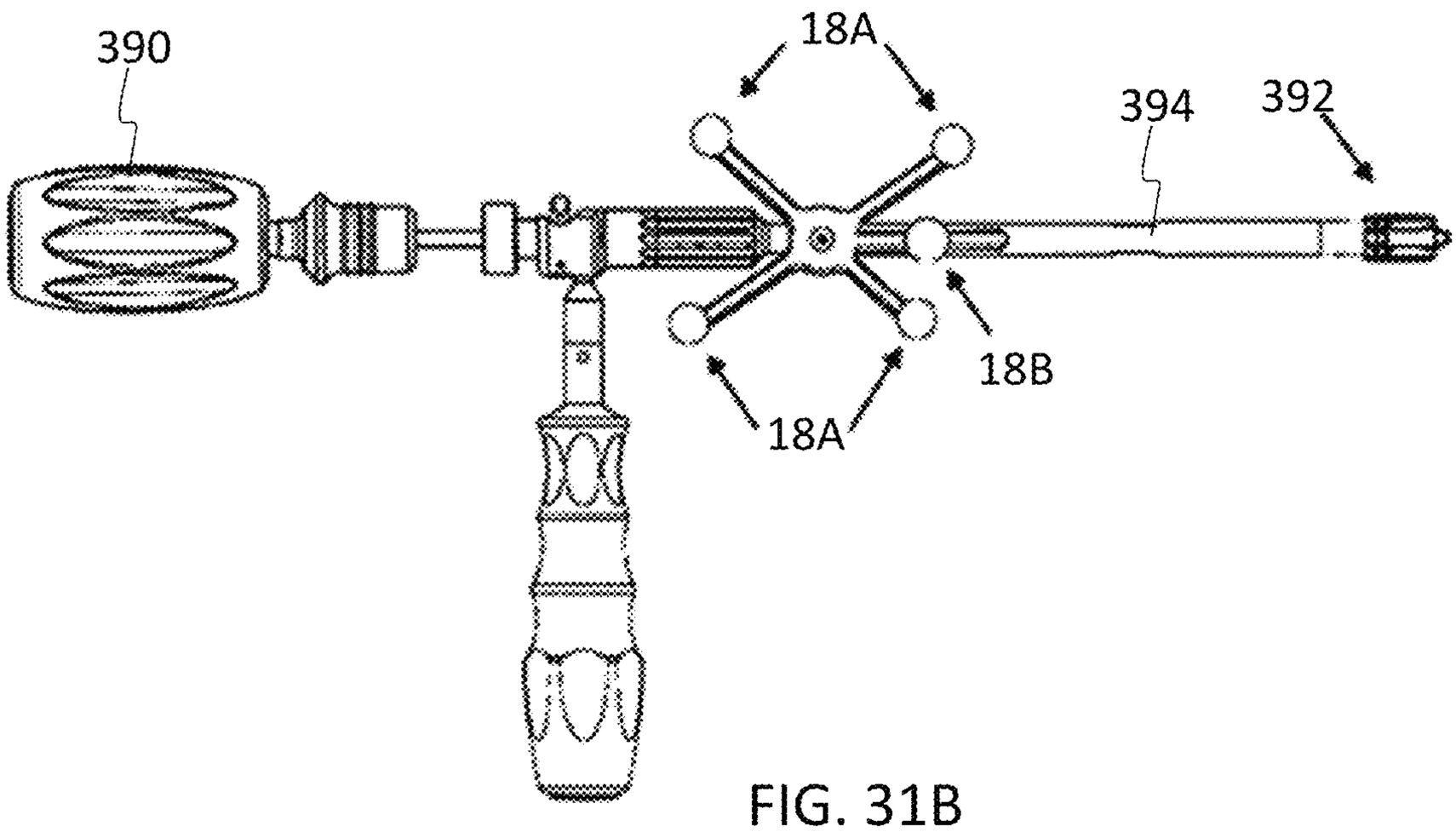

FIG. 31B

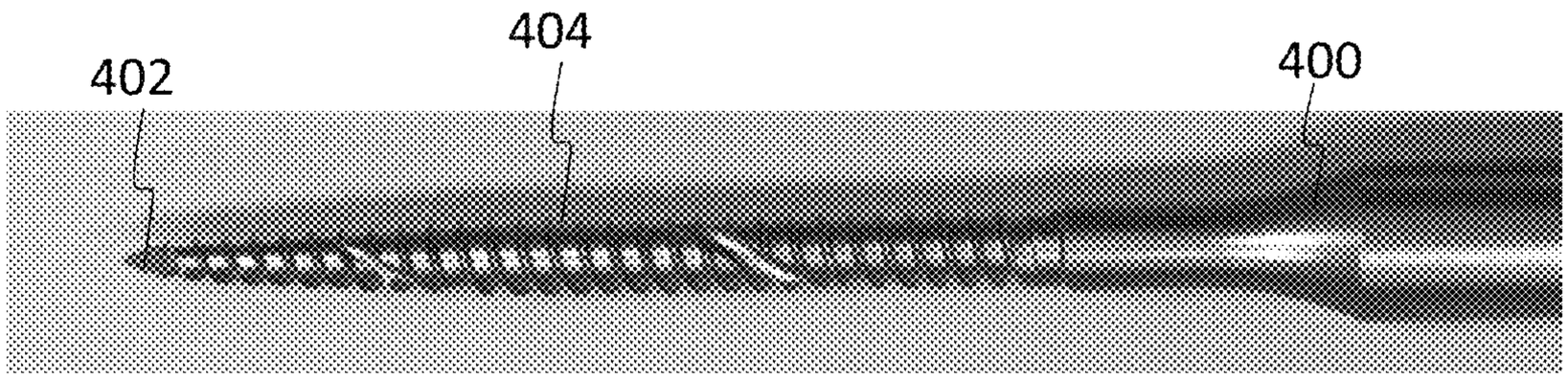

FIG. 32A

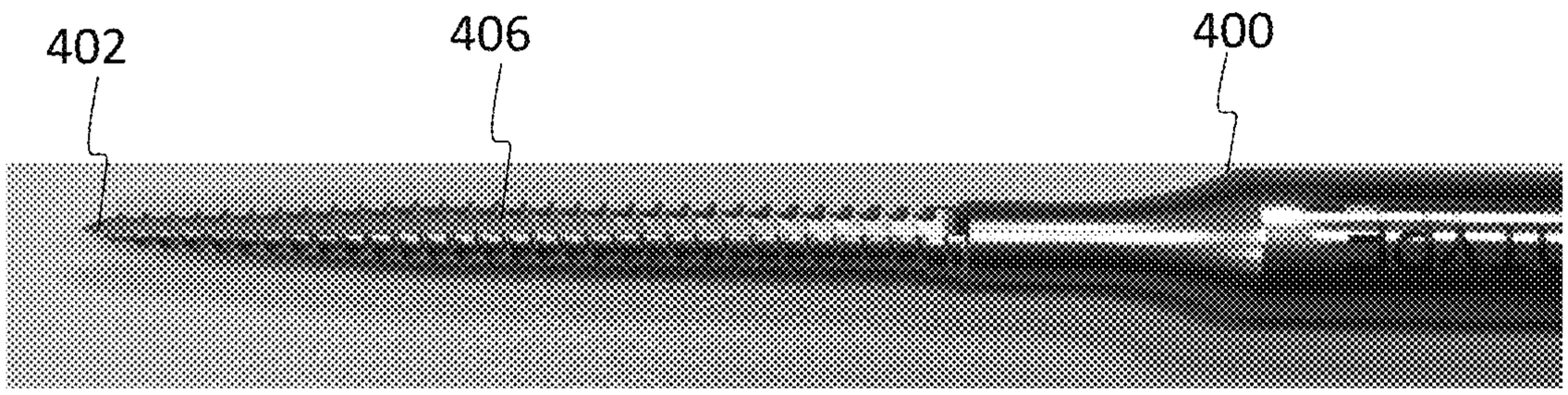

FIG. 32B

ROBOTIC NAVIGATIONAL SYSTEM FOR INTERBODY IMPLANTS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application No. 62/872,278 filed on Jul. 10, 2019, which is incorporated by reference herein in its entirety for all purposes.

FIELD

The present disclosure relates to systems and methods for improved robot-assisted surgery, and, in particular, navigated surgical instruments for access, preparation, and/or placement of interbody fusion devices.

BACKGROUND

Position recognition systems are used to determine the position of and track a particular object in 3-dimensions (3D). In robot-assisted surgeries, for example, certain objects, such as surgical instruments, need to be tracked with a high degree of precision as the instrument is being positioned and moved by a robot or by a physician, for example.

Infrared signal-based position recognition systems may use passive and/or active sensors or markers for tracking the objects. In passive sensors or markers, objects to be tracked may include passive sensors, such as reflective spherical balls, which are positioned at strategic locations on the object to be tracked. Infrared transmitters transmit a signal, and the reflective spherical balls reflect the signal to aid in determining the position of the object in 3D. In active sensors or markers, the objects to be tracked include active infrared transmitters, such as light emitting diodes (LEDs), and thus generate their own infrared signals for 3D detection.

With either active or passive tracking sensors, the system then geometrically resolves the 3-dimensional position of the active and/or passive sensors based on information from or with respect to one or more of the infrared cameras, digital signals, known locations of the active or passive sensors, distance, the time it took to receive the responsive signals, other known variables, or a combination thereof.

There is a need to provide improved systems and methods for robot-assisted surgeries, improved navigation of surgical instruments, and/or improved hardware and software for access, preparation, and/or placement of interbody fusion devices, for example.

SUMMARY

To meet this and other needs, devices, systems, and methods for accessing, preparing, and placing interbody fusion devices are provided. A surgical robotic system is provided which assists a user with one or more surgical procedures. Navigable instrumentation, which includes instruments capable of being navigated, and navigation software allow for the navigated placement of interbody fusion devices or other surgical devices. The interbody implant navigation may involve navigation of access instruments (e.g., dilators, retractors, ports), disc preparation instruments, trials, inserter instruments, and the like. The system allows for locating anatomical structures in open or minimally invasive (MIS) procedures and navigation of surgical instruments and interbody fusion devices.

According to one embodiment, a surgical robot system includes a robot having a base, including a computer, a display electronically coupled to the computer, a robot arm electronically coupled to the computer and movable based on commands processed by the computer, an end-effector electronically coupled to the robot arm, the end-effector including a quick-connector, an articulating arm having a first end coupled to the end-effector by the quick-connector and a second end, an access instrument coupled to the second end of the articulating arm, and a camera configured to detect one or more tracking markers. The access instrument may be a retractor or access port, for example.

The surgical robot system may include one or more of the following features. The end-effector may be a motion lock end-effector configured to prevent motion of the robot arm when attached to the robot arm. The quick-connector may include a male portion receivable within a female portion within the first end of the articulating arm. The articulating arm may include a release button configured to allow for quick attachment and detachment of the articulating arm to the end-effector. The end-effector may connect to the robot arm by clamping over a sterile arm drape. The second end of the articulating arm may include a threaded attachment mount for attachment to the access instrument. The articulating arm may include a plurality of joints that are configured to be locked and unlocked by a locking knob.

According to one embodiment, a robotic navigation system includes a robot and at least one navigable instrument. The robot may include a base, including a computer, a display electronically coupled to the computer, a robot arm electronically coupled to the computer and movable based on commands processed by the computer, an end-effector electronically coupled to the robot arm, the end-effector including a quick-connector, an articulating arm having a first end coupled to the end-effector with the quick-connector and a second end, an access instrument coupled to the second end of the articulating arm, and a camera configured to detect one or more tracking markers. The navigable instrument may include an array of tracking markers trackable by the camera. The navigable instrument may be configured to access, prepare, and/or place an interbody implant. For example, the navigable instrument may be a trial, cup curette, ring curette, cobb, elevator, osteotome, rasp, rake, sizer, shaver, paddle distractor, scraper, dilator, or inserter.

According to one embodiment, a method of robotic navigation may include one or more of the following steps: navigating a dilator including an initial dilator and a tracking array having a plurality of tracking markers to a position based on output from a robot comprising a computer, a display electronically coupled to the computer, and a camera configured to detect the tracking markers; removing the tracking array from the initial dilator; inserting subsequent dilators to prepare an access space; re-attaching the tracking array to the one of the dilators to track the position while placing an access instrument at the access space; and connecting the access instrument to an articulating arm coupled to an end-effector mounted on an arm of the robot. In this method, the initial dilator may be directly navigated and the access instrument may be indirectly navigated to the surgical site.

According to another embodiment, a robotic navigation system includes a robot and a navigable inserter. The navigable inserter may include a sleeve having a longitudinal axis, a rotatable body coupled to the sleeve, and an array of tracking markers connected to the rotatable body. The rotatable body may be configured to rotate about the longitudinal

axis such that the array is viewable by the camera. The inserter may be a threaded or forked inserter, for example. The threaded inserter may include a threaded rod and a driver shaft positionable through the body and the sleeve. The threaded rod may terminate with a distal threaded tip configured to engage an implant. The forked inserter may include a forked rod positionable through the body and the sleeve. The forked rod may terminate with a distal forked tip configured to engage an implant.

The inserter may include one or more of the following features. The rotatable body may include a cavity that houses a translating member including a tapered key. The tapered key may be configured to mate with one or more keyseats in the sleeve of the inserter. A spring may be positioned along the translating member, and the spring may provide force for holding the key in the keyseat. The rotatable body may include a button. When the button is depressed, the spring is compressed and the tapered key translates away from the keyseat, thereby allow the rotatable body and array to rotate. When the button is released, the key engages with the keyseat, thereby locking the rotatable body and the array. The array may have a first index position and a second index position 180 degrees opposite to the first index position. The rotatable body may include a locknut and a spring positioned in an axial direction concentric with the longitudinal axis. The rotatable body may include two tapered surfaces and the sleeve may include two corresponding tapered surfaces such that when the tapered surfaces mate together, the rotatable body and array are locked in position. When the locknut is in a downward position, the tapered surfaces mate and the rotatable body and array are locked, and when the locknut is in an upward position, the tapered surfaces separate and the rotatable body and array are free to rotate.

According to another embodiment, a method of robotic navigation may include navigating an inserter comprising a sleeve having a longitudinal axis, a rotatable body coupled to the sleeve, and an array of tracking markers connected to the rotatable body to a position based on output from a robot comprising a computer, a display electronically coupled to the computer, and a camera configured to detect the tracking markers; and rotating the rotatable body and array such that the tracking markers are in a line of sight of the camera. The array may be moved into one of two index position 180 degrees opposite to one another or into one of four index positions 90 degrees apart from one another, for example.

According to another embodiment, a robotic navigation system includes a robot and a navigable instrument. The navigable instrument may include a handle having a longitudinal axis, a body coupled to the handle, an array of tracking markers connected to the body with an array post, and a detachable shaft and/or a detachable tip configured to perform a surgical function. For example, the tip may be a trial, cup curette, ring curette, cobb, elevator, osteotome, rasp, rake, sizer, shaver, paddle distractor, or scraper.

The navigable instrument may include one or more of the following features. The shaft may include an extension configured to be received in a bore within the handle, and the shaft may include a radial shoulder and a transition between the radial shoulder and the extension. The transition may include a cross-pin configured to be received in one or more slots in the handle. The shoulder may include one or more tapered surfaces and the handle may include one or more corresponding tapered surfaces. When the shaft is connected to the handle, the tapered surfaces engage thereby constraining movement of the shaft relative to the handle. The extension may include a recess and the handle may include a latch configured to be positioned within the recess, thereby locking the handle to the shaft.

According to yet another embodiment, a navigable trial includes a trial shaft and a detachable trial head. The trial shaft includes a hook at its distal end with a pin and a moveable plunger extending through the shaft. The trial head includes a first opening configured to receive the moveable plunger and a second opening configured receive the pin of the hook. When the plunger is positioned within the first opening in trial head, the trial head is locked in place. The trial head is fixed rotationally by the hook and plunger, which allows the trial to be manipulated inside the disc space.

According to yet another embodiment, a navigable trial includes a trial shaft and an expandable trial head. The navigable trial includes an array with a plurality of fixed markers and a moveable marker configured to slide within a pre-determined path to provide feedback on a height of the expandable trial head, wherein translation of the moveable marker may correspond to the height of the trial head.

Also provided are kits including navigable dilators, navigable access and trialing instruments, navigable inserters, retractors and access ports, implants and fusion devices of varying types and sizes, k-wires, and other components for performing the procedures.

DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a surgical robotic system in accordance with an exemplary embodiment;

FIG. **2** provides a close-up view of the surgical robotic system of FIG. **1** configured for performing an operation on a patient;

FIG. **3** is an end-effector for connecting an articulating arm to the surgical robotic system;

FIGS. **4**A-**4**C are steps depicting coupling the end-effector of FIG. **3** to the robotic arm of the surgical robot;

FIG. **5** illustrates an embodiment of an articulating arm which serves as a link between the robotic arm of the surgical robot and an access instrument, such as a retractor or access port;

FIGS. **6**A-**6**B show an embodiment of a navigable instrument and array handle assembly having a quick connect feature configured for use with the robotic system;

FIGS. **7**A-**7**L show a plurality of different instruments or a kit including disc preparation and trial instruments;

FIGS. **8**A-**8**E show alternative embodiments of the array handle assemblies;

FIGS. **9**A-**9**F show a plurality of different array handles or a kit including straight handles and T-handles;

FIGS. **10**A-**10**G show embodiments of interbody inserters with different index positions;

FIGS. **11**A-**11**E provides a plurality of different interbody inserter instruments or a kit including interbody inserters with different instrument connection features;

FIGS. **12**A-**12**B show an embodiment of a navigable inserter assembly with a threaded-style connector;

FIGS. **13**A-**13**B show an embodiment of a navigable inserter assembly with a forked-style connector;

FIGS. **14**A-**14**G provide an embodiment of a navigable dilator array with an initial dilator;

FIGS. **15**A-**15**D provide embodiments of inserter verification adapters suitable for verifying the navigable instruments prior to use;

FIGS. **16**A-**16**C show embodiments of verification of the interbody inserter;

FIGS. **17**A-**17**B show embodiments of dynamic reference bases (DRB);

FIGS. **18**A-**18**D show one or more steps that may be used in planning for and conducting the robot-assisted surgery;

FIGS. **19**A-**19**C show one or more steps that may be used in performing the robot-assisted surgery;

FIGS. **20**A-**20**G depict examples of software user interfaces that may be utilized for instrument planning, setup and access, and/or throughout navigation of the surgical procedure;

FIGS. **21**A-**21**H provide another embodiment of a navigated dilator holder;

FIGS. **22**A-**22**C depict embodiments of navigable instruments with detachable replacement tools and/or instrument tips;

FIGS. **23**A-**23**E depict embodiments of quick connect and release mechanisms for the navigated instruments;

FIGS. **24**A-**24**B show an embodiment of a navigated instrument handle with an array configured to index between rotational positions to align the instrument to desired camera locations;

FIGS. **25**A-**25**C provide another embodiment of a navigated instrument handle with a rotatable array mechanism;

FIGS. **26**A-**26**C shows another embodiment of a navigable implant inserter with a rotatable array mechanism;

FIGS. **27**A-**27**C provide another embodiment of a rotatable array mechanism;

FIGS. **28**A-**28**D provide embodiments of identification of instrument orientation using inline arrays;

FIGS. **29**A-**29**G include embodiments of navigable modular trials;

FIGS. **30**A-**30**B show an embodiment of a navigable fixed trial;

FIGS. **31**A-**31**B show an embodiment of a navigable expandable trial; and

FIGS. **32**A-**32**B show embodiments of navigable awl-tip taps.

DETAILED DESCRIPTION

It is to be understood that the present disclosure is not limited in its application to the details of construction and the arrangement of components set forth in the description herein or illustrated in the drawings. The teachings of the present disclosure may be used and practiced in other embodiments and practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms "mounted," "connected," "supported," and "coupled" and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings. Further, "connected" and "coupled" are not restricted to physical or mechanical connections or couplings.

The following discussion is presented to enable a person skilled in the art to make and use embodiments of the present disclosure. Various modifications to the illustrated embodiments will be readily apparent to those skilled in the art, and the principles herein can be applied to other embodiments and applications without departing from embodiments of the present disclosure. Thus, the embodiments are not intended to be limited to embodiments shown, but are to be accorded the widest scope consistent with the principles and features disclosed herein. The following detailed description is to be read with reference to the figures, in which like elements in different figures have like reference numerals. The figures, which are not necessarily to scale, depict selected embodiments and are not intended to limit the scope of the embodiments. Skilled artisans will recognize the examples provided herein have many useful alternatives and fall within the scope of the embodiments.

Turning now to the drawing, FIGS. **1** and **2** illustrate a surgical robot system **10** in accordance with an exemplary embodiment. Surgical robot system **10** may include, for example, a surgical robot **12**, one or more robot arms **14**, a base **16**, a display or monitor **20** (and optional wireless tablet), an end-effector **22**, for example, for securing an articulating arm **24**, and one or more tracking markers **18**. The surgical robot system **10** may include a patient tracking device **26** including one or more tracking markers **18**, which is adapted to be secured directly to the patient **2** (e.g., to the bone of the patient **2**).

The surgical robot system **10** may also utilize a camera **30**, for example, positioned on a camera stand **32**. The camera stand **32** can have any suitable configuration to move, orient, and support the camera **30** in a desired position. The camera **30** may include any suitable camera or cameras, such as one or more infrared cameras (e.g., bifocal or stereophotogrammetric cameras), able to identify, for example, active and passive tracking markers **18** in a given measurement volume viewable from the perspective of the camera **30**. The camera **30** may scan the given measurement volume and detect the light that comes from the markers **18** in order to identify and determine the position of the markers **18** in three-dimensions. For example, active markers **18** may include infrared-emitting markers that are activated by an electrical signal (e.g., infrared light emitting diodes (LEDs)), and passive markers **18** may include retro-reflective markers that reflect infrared light (e.g., they reflect incoming IR radiation into the direction of the incoming light), for example, emitted by illuminators on the camera **30** or other suitable device.

The surgical robot **12** is able to control the translation and orientation of the end-effector **22**. The robot **10** may be able to move end-effector **22** along x-, y-, and z-axes, for example. The end-effector **22** can be configured for selective rotation about one or more of the x-, y-, and z-axis, and a Z Frame axis (such that one or more of the Euler Angles (e.g., roll, pitch, and/or yaw) associated with end-effector **22** can be selectively controlled). In some exemplary embodiments, selective control of the translation and orientation of end-effector **22** can permit performance of medical procedures with significantly improved accuracy.

The robotic positioning system **12** includes one or more computer controlled robotic arms **14** to assist surgeons in planning the position of stereotaxic instruments relative to intraoperative patient images. The system **10** includes 2D & 3D imaging software that allows for preoperative planning, navigation, and guidance through a dynamic reference base, navigated instruments and positioning camera **30** for the placement of spine, orthopedic, or other devices. Further details of surgical robotic and navigation systems can be found, for example, in U.S. patent publication No. 2019/0021795 and U.S. patent publication No. 2017/0239007, which are incorporated herein by reference in their entireties for all purposes.

With further emphasis on FIG. **2**, the robot **12** and/or surgeon may position the end effector **22** and the articulating arm **24** into a desired position for mounting an access instrument **34**, such as a retractor or port system, through which the surgeon can use navigated instruments to perform

surgery. Power to the robotic arms **14** may be shut off once the motion lock end effector **22** is attached to the arm **14**. In one embodiment, this gives the surgeon full control of the instruments, and the system **10** does not perform or physically guide the surgery. The navigation camera **30** tracks the position of instruments in real time and provides an image on the monitor **20**, along with the patient's images, for example, to provide guidance to the surgeon.

Turning to FIGS. **3-5**, the motion lock end-effector **22** and articulating arm **24** are shown in greater detail. The motion lock end-effector **22** and articulating arm **24** provide a rigid attachment connection for an access instrument **34**, such as a surgical retractor (shown in FIG. **19**B) or access port (shown in FIG. **19**C). Alternatively, a standard table mounted articulating arm, retractor, or port may be used if desired. The motion lock end-effector **22** prevents robotic arm motion when attached to the robot arm **14**. The end-effector **22** provides a rigid quick-connect connection to the articulating arm **24**, which is used to rigidly attach and position the access instrument **34** (e.g., retractor or arm-mounted port).

As shown in FIGS. **4**A-**4**C, the end-effector **22** connects to the robotic arm **14** by clamping over the sterile arm drape **28**. The end-effector **22** includes a male portion **23** which is receivable within a female portion within one end of the articulating arm **24**. The articulating arm **24** attaches to the male portion **23** of the end-effector **22** with a release button **36**. The release button **36** allows for quick attachment and detachment of the articulating arm **24** to the end-effector **22**. The attachment mount **38** on the opposite end of the articulating arm **24** attaches to the access instrument **34** (e.g., retractor or arm-mounted port). The distal end of the articulating arm **24** may have a threaded attachment mount **38** for connection to retractor systems or ports **34**. Once the articulating arm **24** is positioned and an access instrument **34** is attached thereto, the locking knob **40** may be tightened to secure the assembly. The articulating arm **24** serves as a link between the robotic arm **14** and the surgical retractor or access port **34**. The articulating arm **24** may have several joints which are locked and unlocked by tightening or loosening the locking knob **40**, allowing for quick adjustments to retractor position, similar to standard table mounted retractor arms.

In this manner, the robotic arm **14** may be used as a rigid fixation point for a retractor or port **34** to provide access to the spine. Once the sterile drape **28** is fitted over the robot **12**, the robotic arm **14** can be moved into position. The end-effector **22** may be attached to the robotic arm **14** through the interface plate, over the sterile drape **28**. A magnetic assist may help to position and self-align the end-effector **22**. The drape-friendly clamp **29** allows the end effector **22** to be removed and reattached up to three times in a procedure without damaging the drape **28**. The end-effector **22** is powered wirelessly from the robotic arm **14**. When attached to the robotic arm **14**, the motion lock end-effector **22** sends a signal to the system **10** to restrict all motion (e.g., stabilizers and robotic arm **14**) and prevent unintended movement as a safety feature while the access instrument **34** (e.g., retractor blades or access port) is used in the patient **2** and the operation is performed.

Turning now to FIGS. **6**A-**6**B, a navigable instrument **50** is shown. Navigated instruments **50** may include dilators, disc preparation instruments (e.g., curettes, Cobb elevators, rasps, scrapers, etc.), trials, and inserters, for example. The navigable instrument **50** may include a handle portion **52**, a shaft portion **54**, and an array **56** including one or more tracking markers **18** for tracking the instrument **50**. The array **56** may be affixed to the handle body **52** with an array post **64**. The array **56** may be configured to rotate about the central axis of the handle **52**. The handle portion **52** may include straight and T-handle styles. The shaft portion **54** may have a tip **58** at its distal end configured to perform one or more functions and a quick-connector **60** at its proximal end configured to quickly connect and disconnect from the handle portion **52**, thereby providing for rigid attachment to the array handle assembly. A slot **62** in the shaft **54** retains the instrument and a pin **63** controls orientation. Instruments **50** are assembled with the selected array handle **52** by inserting the instrument shaft **54** into the handle **52** with the alignment pin **63** and groove **62** aligned until fully seated. When fully inserted, an audible click is heard and the instrument **50** is locked.

As shown in FIGS. **7**A-**7**L, the disc preparation and trial instruments **50** may include trials (shown in FIGS. **7**A and **7**B), cup curettes (shown in FIG. **7**C), ring curettes (shown in FIG. **7**D), cobbs (shown in FIG. **7**E), elevators (shown in FIG. **7**F), osteotomes (shown in FIG. **7**G), rasps (shown in FIG. **7**H), rakes (shown in FIG. **7**I), sizers/shavers (shown in FIG. **7**J), paddle distractors (shown in FIG. **7**K), scrapers (shown in FIG. **7**L), and other suitable instruments. Instruments **50** for lateral use may be longer in length, and those for posterior use may be shorter in length. A kit may be provided with a variety of different instruments **50** in various sizes.

Disc preparation and trial instruments **50** may be used interchangeably with various array handles **52**. The user may assign an instrument to an array handle **52** in the software prior to use. Representative models of disc preparation and trial instruments **50** are loaded in the software and may be selected from a list of instruments in the user interface.

Turning to FIGS. **8**A-**8**E, the instruments **50** may be used with detachable array handles **52** that may have integrated arrays **56** for navigation. The instruments **50** may also be used freehand without navigation, if desired. Each instrument shaft **54** and corresponding array handle **52** are assembled prior to use. The array handles **52** may come in straight and T-styles, for example, to suit user preference. Each array **56** has a unique marker pattern that is recognized by the system **10**. Arrays **56** may have one or more posts **66** (e.g., four posts **66**) for attaching reflective markers **18** thereto. Each array **56** has a unique pattern which allows the system **10** to identify the array **56**, and thereby identify the type of instrument **50**. The array handles **52** are attached to the shafts **54** of the disc preparation instruments and trials for navigation. The handles **52** may include a release button **68** for removing the shafts **54** of the disc preparation instruments or trials. As shown in FIG. **8**D, the array handle **52** may be verified through the use of an instrument and verification divot **70**. A verification divot **70** located on the array post **64** may be used to verify other navigated instruments, for example, by placing the instrument tip **58** into the divot **70**.

According to one embodiment shown in FIGS. **9**A-**9**F, there are six different arrays **56** which may be distinguished to the user by a color and/or an etched number. The handles **52** may include a straight handle **52** with a red array **56** (shown in FIG. **9**A), a straight handle **52** with a gold array **56** (shown in FIG. **9**B), a straight handle **52** with a green array **56** (shown in FIG. **9**C), a straight handle **52** with a blue array **56** (shown in FIG. **9**D), a T-handle **52** with a purple array **56** (shown in FIG. **9**E), and a T-handle **52** with a grey array **56** (shown in FIG. **9**F), for example. Each array pattern may include four posts **66** for mounting reflecting markers **18** that are tracked by the optical cameras **30**. The arrange-

ment of these posts **66** is unique for each array handle **52**. The array plates **56** may each have a unique color and laser marked number (e.g., Red "1"). These indicators allow the user to quickly assign a disc preparation instrument shaft **54** to the corresponding array handle **52** in the software (e.g., Red 1-Cobb 10 mm). Once the array handle **52** is verified, the instruments **50** may be exchanged during the procedure. A new instrument **50** must be reassigned and the array position adjusted, in order for the instrument **50** to be correctly displayed for navigation. Various instruments **50** may be navigated during a procedure.

With emphasis on FIGS. **10**A-**10**B, the array handles **52** allow the array **56** to rotate about the central axis of the handle **52** to ensure that the array **56** is in view of the camera **30** or to change the orientation of the instrument **50** relative to the patient anatomy and the array **56**. The user may press the rotation index button **72** to rotate the array **56** until it clicks into a new index position **74**, as desired. The index positions **74** may be etched on the handle **52** with an indicator **76**, for example. A first index position **74** is identified by the letter A (shown as indicator **76** in FIG. **8**A) that aligns with a rectangular marking next to the divot **70**. As shown in FIG. **10**A, the T-handles **52** may index the instrument **50** to four index positions **74** (A, B, C, D) that are located 90° apart. As shown in FIG. **10**B, the straight handles **52** may index the instrument **50** to two index positions **74** (A, C) that are 180° apart. Each index position **74** may be denoted on the array handle **52** by an indicator letter **76** (A, B, C, D, or A, C, respectively) corresponding with the respective index positions **74**. When the instrument shaft **54** and array handle **52** are assembled, the index position **74** starts at "A", as shown on the position identifier **76** on the handle **52**. All instruments **50** may be verified and initially displayed on the software in the "A" index position **74**. The user then inputs the index orientation into the software when the array **56** is rotated to a new index position **74**, to ensure the displayed instrument model is oriented in the same position as the actual instrument **50**.

The array **56** can be rotated relative to the shaft **54** to ensure that the array **56** is in view of the camera **30**. The user presses the index button **72** and rotates the array **56** around the handle **52** until it clicks into one of the index positions **74**. The index position **74** starts at "A". When the index position **74** is changed to "B", "C", "D" (or later back to "A"), the user enters the position on the touchscreen monitor **20** of the robot **12**. This allows the monitor **20** to display the correct orientation of the corresponding instrument model. Although two or four index positions **74** are shown in the embodiments, it will be appreciated that any suitable number and location of index positions **74** may be used.

All of the array handles **52** may have the same quick connect and release attachment mechanism. This allows any disc preparation or trial instrument shaft **54** to be assembled to any array handle **52**. The user assigns an instrument **50** to each handle array **56** in the software. A release button **68** on the array handle **52** allows the instrument shaft **54** to be inserted or removed when pressed. A slot **62** may be incorporated into the connection mechanism which mates with a pin on all mating disc preparation and trial instruments to control rotational orientation.

Turning to FIG. **10**C, a navigable interbody inserter instrument or interbody inserter **80** is further described. Navigable interbody inserters **80** may be configured to install lumbar interbody implants used in transforaminal (TLIF), posterior (PLIF), and lateral (LLIF) interbody fusion procedures, for example. It is also contemplated that the inserters **80** may be configured to install other interbody devices or implants. Depending on the implant design, the interbody inserters **80** may have a forked tip **96** or threaded tip **98** to hold the interbody implant or may be otherwise configured to retain the implant.

The interbody inserters **80** may have an array plate **82**, a shaft or sleeve **84**, a rotatable body **88**, and an array post **90** connecting the array plate **82** to the body **88**. For the threaded inserters **80**, the inserter **80** may include a threaded rod **100** and driver shaft **102** positionable through the inserter body **88** and through the sleeve **84**. The threaded rod **100** may terminate with a distal threaded tip **98** configured to engage the implant. For the forked inserters **80**, the inserter **80** may include a forked rod **104** positionable through the inserter body and the sleeve **84**, and may terminate with a distal forked tip **96** configured to engage the implant.

In one embodiment, the array post **90** may be permanently integrated to the body **88** of the inserter **80** with the body **88** free to rotate about the shaft or sleeve **84** of the inserter **80**. The array plate **82** may have one or more posts **86** (e.g., four posts **86**) for mounting reflecting markers **18** that are tracked by the optical camera **30**. The array pattern may be unique to inserters **80**. For example, all inserters **80** may have the same array pattern, regardless of which implant is being placed. The inserter array pattern may be different than the pattern on other array instruments (e.g., arrays **46**, dilator array **114**).

With emphasis on FIGS. **10**D-**10**G, the rotatable body **88** (and attached array **82**) may be permitted to rotate about the central axis sleeve **84** to ensure that the array **82** is in view of the camera **30** or to change the orientation of the inserter **80** relative to the patient anatomy. The user may press a rotation index button **94** and/or manipulate a knob **92** to rotate the array **82** until it is oriented into a new index position **74**, as desired. The arrays **82** on the inserters **80** may be indexed to two index positions **74** (A, C, respectively) as shown in FIG. **10**B. The index positions **74** may be identified on the instrument **80** with laser marking that are 180° apart in the same manner described for instrument **50**. This allows the arrays **82** to be rotated, for example, to ensure that the array **82** is in view of the camera **30**. To switch between index positions **74**, the user may loosen the threaded knob **92** to rotate the array **82**, for example, 180° to the opposite location. Then, the knob **92** may be tightened to secure the position. In another embodiment, the user presses an index button **94** to rotate the array **82**. In FIGS. **10**E and **10**G, the inserters **80** are shown at the index position **74** identified as position "A". In FIGS. **10**D and **10**F, the index position **74** of the inserters **80** are changed to position "C". When the index position **74** is changed to "C" (or later back to "A"), the user enters the position on the monitor **20**. This allows the monitor **20** to display the correct orientation of the corresponding instrument model.

Turning to FIGS. **11**A-**11**E, several embodiments of inserters **80** are shown. In FIG. **11**A, the inserter **80** may include a forked distal tip **96** configured to retain a static posterior interbody spacer. In FIG. **11**B, the inserter **80** may include a threaded distal tip **98** configured to retain an articulating expandable TLIF spacer. In FIG. **11**C, the inserter **80** may include a forked tip **96** configured to retain an expandable lateral lumbar fusion device. In FIG. **11**D, the inserter **80** may include a forked tip **96** configured to retain an expandable lumbar fusion implant. In FIG. **11**E, the inserter **80** may include a threaded tip **98** configured to retain expandable interbody fusion spacer with integrated fixation. Although the forked **96** and threaded **98** embodiments are shown, it will be appreciated that the distal end of the

inserter **80** may be configured in any way to hold an implant during the procedure. Based on the selected implant system, the implant inserter **80** corresponding to the implant system is identified in the software. Implant inserters **80** may include the integrated arrays **82** for navigation by the system **10**.

Turning to FIGS. **12**A-**13**B, the inserters **80** may be assembled as follows. With emphasis on FIGS. **12**A-**12**B, to assemble the threaded inserter **80**, the sleeve **84** may be inserted into the array assembly and the threaded rod **100** and driver shaft **102** may be inserted into the inserter body **88** and through the sleeve **84**. One or more prongs **85** of the sleeve **84** may be aligned with the inserter body **88** to insert the sleeve **84** therein. The knob **89** may be rotated clockwise and threaded to the sleeve **84** to secure the assembly. With emphasis on FIGS. **13**A-**13**B, to assemble the pronged inserter **80**, the sleeve **84** may be inserted into the array assembly and the forked shaft **104** may be inserted into the inserter body **88** and through the sleeve **84**. One or more prongs **85** of the sleeve **84** may be aligned with the inserter body **88** to insert the sleeve **84** therein. The knob **89** may be rotated clockwise and threaded to the sleeve **84** to secure the assembly.

Non-navigated instruments, such as tightening wrenches and torque-limiting drivers (for expandable device inserters) may be provided to work specifically with the interbody inserters **80**. These ancillary instruments serve the same function as the instruments that work with the corresponding non-navigated interbody inserters. These non-navigated instruments are not rendered on patient imagery and are may be used to support mechanical functionality of the inserters **80**, for example.

Turning now to FIGS. **14**A-**14**G, a navigable dilator instrument or dilator **110** is shown. The navigable dilator **110** may include an initial dilator **112** and a dilator array **114** configured to be tracked by the robotic navigation system **10**. The dilator array **114** may include a unique array pattern, a cavity or attachment window **116**, a release button **118**, and a verification divot **120**. Similar to arrays **56** and **82**, array **114** may have one or more posts **122** (e.g., four posts **122**) for attaching tracking markers **18** thereto. The array **114** has a unique pattern which allows the system **10** to identify the array **114** and thereby identify the dilator **110** for navigation. The verification divot **120** may be used to verify with other navigated instruments **50**, by placing the instrument tip **58** into the divot **120**. The verification divot **120** may be located on the top of the array **114**, for example.

The dilator array **114** may attach to an initial dilator **112**. The initial dilator **112** may include cannulas, such as 2 mm cannulas, insulated cannulas A, stainless steel cannulas A, or other suitable cannulas or dilators. As shown in FIG. **14**D, to assemble the initial dilator **112** and dilator array **114**, the release button **118** may be pressed to open the attachment window **116**. The dilator **112** may be inserted into and through the window **116**. As shown in FIG. **14**E, a side viewing window **124** may be checked to ensure the dilator **112** is fully inserted in the array **114**.

As shown in FIGS. **14**F-**14**G, the markers **18** (e.g., disposable reflective markers) may be attached to each of the marker posts **122** of the array **114**. As shown in FIG. **14**G, to assemble, the markers **18** are fully seated on the posts **122**. It will be appreciated that the markers **18** may be similarly affixed to the posts **66**, **86** of similar arrays **56**, **82** described herein.

The dilator array **114** may be attached to an initial dilator **112** for navigation by the system **10**. The user may select the specific initial dilator **112** to be used with the array **114** on the software interface. When the dilator **112** and array **114** are assembled and verified, a representative image of the selected dilator **110** is overlaid on the patient's anatomical images during soft tissue dilation. Once the dilator **110** is placed, sequential dilation may be performed with non-navigated cannulas, if desired.

Turning now to FIGS. **15**A-**15**D, embodiments of verification adapters **130** are described for verification, for example, as an alternative to an instrument **50** (e.g., disc preparation instrument or trial) or the inserter **80** with implant for verification. As best seen in FIG. **15**C, each of the adapters **130** has a pointed tip **132** (e.g., a conical tip) that fits into the verification divot **70**, **120** located on other array instruments **50**, **110**. Each type of inserter **80** mates with a specific verification adapter **130** as identified on the adapter **130**. The proximal end of each adapter **130** has one or more mating features **134** (e.g., protrusions, recesses, slots) which match the corresponding implant features such that the given inserter **80** is configured to hold the matching adapter **130**.

In one embodiment, the verification adapter **130** may be used to replace the instrument shaft **54** attached to an array handle **52**. In this case, the adapter **130** is placed onto the array handle **52** for verification. After verification, the adapter **130** may be removed and the instrument shaft **54** is placed onto the handle **52** for its intended function. The verification adapter **130** may have a conical tip **132** that fits easily inside the verification divots **70** of the array handles **52** or any instrument with a verification divot **70**, **120**. The adapter **130** may be provided as an option to verify instruments **50** that do not have a convenient tip **58** for verification, such as a curved curette or osteotome.

In another embodiment, shown in FIG. **15**D, the verification adapter **130** may also be used with the inserters **80**. Inserter verification adapters **130** may be used for verification of the interbody inserter instruments **80** prior to use as an alternative to an implant affixed to the inserter **80**. Each adapter **130** corresponds to a specific inserter **80** and implant type. The adapter **130** is placed onto the distal end of the inserter **80** to provide a pointed tip **132** for verification. After verification, the adapter **130** is removed and the desired implant is placed onto the inserter **80** for navigation.

Turning to FIGS. **16**A-**16**C, a verification procedure is described. Any instrument **50** (e.g., disc preparation instrument or trial) or inserter **80** may be placed in the verification divot **70**, **120** of another array handle **52**, dilator array **114**, or other suitable divot for software verification. With emphasis on FIG. **16**A, inserter **80** may be verified by placing the tip **132** of the verification adapter **130** into the verification divot **70** located on another array handle **52**. In FIG. **16**B, inserter **80** may be verified in the software by placing the tip **132** of the verification adapter **130** into the verification divot **120** located on the dilator array **114**. The software verification ensures that both instruments **50**, **80**, **110** are visible, facing the camera **30**, and held steady in a vertical position. The central axis of each array **56**, **82**, **114** should be parallel to one another to complete verification.

As shown in FIG. **16**C, a pop-up screen may appear on the monitor **20** (or other screen) to indicate verification progress. The navigated instruments **50**, **80**, **110** are pre-calibrated with dimensional information stored in the software, including optical marker location, tip location, and verification divot location. Up to six instrument shafts **54** attached to array handles **52** may be verified and navigated at one time. During verification, the predefined dimensional information is used to define instrument position. The user selects an implant family before proceeding to a verification screen.

Once the implant family is selected, the location of the tip **58** of the surgical instrument **50** is known to the software. Arrays and/or integrated instrument arrays **56**, **82**, **114** are verified by the navigation system **10** prior to use. Verification adapters **130** may be attached to the instrument handles **52** or inserters **80** as needed. During accuracy verification (registration), the user holds the tip **58**, **132** of one navigated instrument **50** or inserter **80** to the verification divot **70**, **120** of another array handle **52**, dilator array **114**, or other suitable instrument. Both arrays **56**, **82**, **114** must be visible to the camera **30** and held steady in a vertical position, such that the central axis of each instrument shaft are parallel to each other. Upon completion, the verification result is displayed as success icon (e.g., green circle shown on left side of FIG. **16**C) or a failure icon (e.g., red crossed circle shown on right side of FIG. **16**C).

When attaching the instrument shafts **54** to the array **56**, the same instrument name should be assigned to the corresponding array on the monitor **30**. After verification, the instruments **50** are activated and displayed on the monitor **30**. Array handles **52** and inserters **80** may only require one verification per surgery. After verification, the verification adapter **130** can be removed and the desired instrument shaft **54** or interbody spacer may be attached to an array handle **52** or interbody inserter **80**, respectively. A digital representation of navigated instruments is rendered on registered patient imagery as a simplified 3D drawing depicting instrument-specific details, rather than as a generic instrument. Planned implants (which may not be navigated) are also rendered on patient imagery as simplified 3D drawings, depicting implant-specific details. Non-navigated instruments may not be rendered on patient imagery. Although specific features of verification are described herein, it will be appreciated that additional instruments or configurations may be used to verify components for the surgical procedure.

Turning now to FIGS. **17**A-**17**B, embodiments of dynamic reference bases **140**, **142** (DRBs) are shown. The dynamic reference base **140**, **142** is a patient tracking device **26** including one or more tracking markers **18**, which is adapted to be secured directly to the patient **2** (e.g., to the bone of the patient **2**). The dynamic reference bases **140**, **142** may be used to establish a fixed reference point in the optical space from which all navigation tracking is referenced. An embodiment of dynamic reference base **140** shown in FIG. **17**A allows for two dynamic reference bases **140**, **142** to be used at one time for a longer working distance. The dynamic reference base **140** shown in FIG. **17**A may also be used as the only dynamic reference base **140**, as an alternative to the dynamic reference base **142** shown in FIG. **17**B.

The dynamic reference bases **140**, **142** each include an array body **144** and a clamp mechanism **146**. The dynamic reference bases **140**, **142** attach to a rigid patient fixation device **138**, such as a quattro spike, low profile quattro spike, bone clamp, rod attachment, or the like. The dynamic reference bases **140**, **142** can be adjusted for positioning in the surgical space.

They dynamic reference bases **140**, **142** have arrays **144** with one or more posts **148** (e.g., four posts **148**) for attaching reflective markers **18** thereto. Each array **144** has a unique pattern which allows the system **10** to identify the array **144** and thereby identify the dynamic reference base **140**, **142**. The dynamic reference base **140** has a different array pattern than the dynamic reference base **142** so that it is uniquely identified by the system **10**.

In the embodiment shown in FIG. **17**A, the dynamic reference base **140** includes clamp mechanism **146**, which is configured to be attached to the patient fixation post **138**. The dynamic reference base **140** has a sliding mechanism **150** to clamp onto the post **138** and may be tightened by a driver (e.g., a hexalobular driver). In the embodiment shown in FIG. **17**B, the dynamic reference base **142** has a clamp **146** with a thumb screw **152** that compresses a clasp around the fixation rod. The dynamic reference bases **140**, **142** may be provided non-sterile and sterilized prior to use in surgery. The dynamic reference base **140** may be used alone or in conjunction with the dynamic reference base **142** for long constructs.

Turning now to FIGS. **18**A-**18**D, steps for setting up a navigated surgical procedure are shown. Prior to starting the procedure, a sterile drape **28** is placed over the robotic arm **14**, monitor **20**, and front portion of the base station **16**. Passive markers **18** are added to the arrays **56**, **82**, **114**, **144** of all navigated instruments and devices **50**, **80**, **110**, **140**, **142**. As shown in FIG. **18**A, the surgeon can use planning software to determine the location of interbody implants and instruments on patient images **20**. Planning may be performed before image registration for preoperative imaging workflow or after image registration for intraoperative imaging workflow or 2D imaging workflow. Instrument planning allows the surgeon to plan interbody devices (or screws) with navigated instruments **50**, **80**, **110** by pressing on the foot pedal or confirming on the touch-screen monitor **20** after image registration. The surgeon can plan on the touch-screen monitor **20** as well as on the tablet with preoperative imaging. The implant is selected in the software and moved to the desired location on the patient images.

As shown in FIG. **18**B, once the patient **2** has been prepped and the surgeon is ready to begin, a patient fixation post **138** is secured to the patient's bony anatomy in proximity to the surgical site. As shown in FIG. **18**C, a dynamic reference base **140**, **142** may be attached to the patient fixation post **138**. In addition, a separate surveillance marker **154** may also be secured to the patient's bony anatomy in proximity to the surgical site. The surveillance marker **154** may include a single tracking marker **18** and may be used to provide additional verification that the dynamic reference base **140**, **142** does not move during the procedure.

A specific anatomical position is first registered on the patient **2** in reference to a known coordinate frame in order to track its location. As shown in FIG. **18**D, this may be accomplished by rigidly affixing the dynamic reference base **140**, **142** and intra-op registration fixture **156**, which contains both CT fiducials and passive markers **18**, to the patient attachment instrument **138** (e.g., applicable for the intraoperative CT imaging modality). The dynamic reference base **140**, **142** is rigidly fixed to the patient attachment instrument **138**. The dynamic reference base **140**, **142** is placed in a location that can be easily seen by the camera **30**. The intra-op registration fixture **156** is clamped to the post of the patient attachment instrument **138** with a pivoting arm **158**. The pivoting arm **158** may have six degrees of freedom so that the fixture can be positioned directly over the surgical site.

Turning now to FIGS. **19**A-**19**C, one or more steps for performing the navigated surgical procedure are shown. As shown in FIG. **19**A, if desired, the starting position and trajectory of the access instrument **34** (e.g., retractor shown in FIG. **19**B or port system shown in FIG. **19**C) may be established by navigating the dilator **110**. The dilatory array **114** may be verified by the system **10**. The initial dilator **112** may be navigated to locate the access trajectory. The dilator array **114** may be removed for tissue dilatation. For example, sequential dilation using dilators (cannulas) of increasing

size may be performed by the surgeon. The access instrument **34** may be positioned over the dilators. The articulating arm **24** may be attached to the access instrument **34** and the end-effector **22**, which is coupled to the robot arm **14**. The locking knob **40** may be tightened to secure the articulating arm **24**. Once the access instrument **34** is positioned, any of the navigable instruments **50** and inserters **80** may be utilized as described herein to install the interbody implant.

Turning now to FIGS. **20**A-**20**G, examples of software user interfaces that may be utilized for instrument planning, setup and access, and/or throughout navigation of the surgical procedure are provided. Instruments **50**, **80**, **110** may be navigated freehand during the surgical procedure for preparation and placement of interbody fusion devices. Screws may be placed before or after interbody spacers using various workflows. The position of the instruments **50**, **80**, **110** are tracked by the camera **30**. The surgeon has the same tactile feel of the disc space anatomy and the surgical instruments **50**, **80**, **110** as in a standard surgery. Instruments **50** including trials, cup curettes, ring curettes, cobb elevators, elevators, osteotomes, rasps, rakes, scrapers, sizers/shavers, paddle distractors, and trials, may be used according to standard surgical techniques to place interbody spacers. The position of the navigable instruments **50**, **80**, **110** is monitored in real time. The surgeon manually operates the instruments **50**, **80**, **110** and determines the correct placement and positioning. Surgical instruments **50**, **80**, **110** may be used through the attached access instrument **34** (e.g., retractor or port), if desired.

The robotic software user interfaces are configured to aid the surgeon and staff through a typical procedure. Tabs on the screen **20** may represent each step of the process, as follows: (1) workflow step **162** allows the user to select the implant set and general location of implant placement; (2) verify step **164** allows the user to verify the navigation instruments, for example, to ensure instruments were not damaged since the last use; (3) image step **166** allows the user to import and select the patient images; (4) plan step **168** allows the user to plan implant placement on the patient's medical images; and (5) navigate step **170** shows instrument and implant location on the patient's medical images.

Referring to FIG. **20**A, instrument planning in the workflow step **162** may begin with a screen view **160** with a simulated anatomical view of the spine. In the workflow tab **162**, the desired stage of the procedure (e.g., interbody or screw placement) may be selected in the desired order of operation (e.g., interbody placed first). For each stage, the imaging modality, interbody implant system, and desired interbody level on the anatomical model may be selected. Stages may be added to the workflow by clicking the "Add Stage" button **172** to add a stage to the case. The spinal levels may be selected, for example, by double-clicking on the spinal level indicator circles or bubbles **174** to select or de-select the spinal level for planning. The "Verify Instruments" button **176** may be selected to proceed to advance to the next tab.

Any navigable instrument **50**, **80**, **110** can be used for instrument planning. Instrument planning refers to creating an implant plan by aligning the trajectory of a navigated instrument **50**, **80**, **110** to the desired implant trajectory and confirming this trajectory through a user input. The instrument planning functionality allows the user to select whether the implant plan is created at the tip **58** of the instrument **50**, or at some distance from its tip **58** along its trajectory. The user can select the type and dimensions of the planned implant to best fit the image of patient anatomy. The user navigates instruments **50**, **80**, **110** to the desired location and drops to the implant onto patient images in the software.

Referring to FIG. **20**B, the verify tab **164** displays navigation details including visibility, location and verification status of the instruments **50**, **80**, **110** selected on the workflow tab **162**. Verification may be used, for example, to ensure all instruments **50**, **80**, **110** have not been damaged during handling. All instruments **50**, **80**, **110** with arrays **56**, **82**, **114** may be verified prior to use, either with a verification adapter **130**, instrument **50**, implant, or dilator **110**, as appropriate. The verify tab **164** may show a camera view and instrument status. The camera view is a real-time view from the perspective of the camera **30** with one or more color circles **178** indicating instrument location. A solid colored circle **178** may indicate that the instrument **50**, **80**, **110** is visible by the camera **30**, while a hollow circle may indicate that it is not visible. The colored circle **178** may grow larger as the instrument **50**, **80**, **110** is moved closer to the physical camera **30** and smaller as it moves away from the camera **30**, for example. The ideal distance from the camera **30** is approximately 2 meters or 6 feet, but it will be appreciated that the distances may vary. The instrument status may list each instrument **50**, **80**, **110** and its verification status, with corresponding color circles to identify each instrument **50**, **80**, **110**. The verification status symbols may include a green marker indicating successful verification and a red marker indicating failed verification. The icons for the verify tab **164** may include a back arrow indicating a return to workflow tab **162** and a load scan button for clicking to proceed to the next image tab **166**.

Referring to FIG. **20**C, arrays **56**, **82**, **114** are verified by the navigation system **10** to ensure they have not been damaged during handling, cleaning, or sterilization. The camera **30** detects the unique pattern of reflective markers **18** affixed to the arrays **56**, **82**, **114**. Each array **56**, **82**, **114** must be verified prior to use, by attaching the instrument shaft **54**, verification adapter **130**, implant (for inserter **80**), or dilator **112** (for dilator array **114**), to the array handle **52** or inserter **80** and placing the tip of the assembly into the verification divot **70**, **120** of another array handle **52** or the dilator array **114**. After verification, the verification adapter **130** is removed (if used) and the desired instrument shaft **54** or interbody spacer is attached to the array handle **52** or inserter **80**, respectively. When attaching an instrument shaft **54** to an array handle **52**, the same instrument name should be assigned to the corresponding array in the software. At this point, the virtual instrument or instruments **180** are activated and displayed on the monitor **20**. Once verification is complete, verification status is indicated on the screen **20**. If there is an error, the tip error may be displayed in mm. As shown in FIG. **16**C, the screen view **160** may indicate if verification has failed (e.g., a red crossed circle may be displayed), and verification may be repeated until it is successful (e.g., a green circle may be displayed). When all instruments are successfully verified, the "Load Scan" button may be selected to advance to the next tab.

Turning to FIGS. **20**D and **20**E, the plan step **168** allows for optional planning for interbody implant placement. The plan tab **168** allows the user to plan placement of all virtual interbody implants **182** overlaid on the screen view **160** of the patient images. Implants may be preloaded on the right panel of the screen **160**, based on selections made in the workflow tab **162**. An implant plan may be created by dragging and dropping the desired implant **182** on the patient image, or by navigating an instrument **50**, **80**, **110** to the desired location and dropping an implant **182** in that

location on the patient image. The implant position and size may be adjusted on the planning tab **168**.

In FIG. **20**D, the desired implant label may be selected on the right panel of the screen **20** and dragged onto the image. Once aligned, the planned implant **182** may be released to drop it onto the image **160**. The active implant **182** may be highlighted on the right panel during planning. When selected, the icon may switch to the hand icon. In FIG. **20**E, the instrument planning icon on the right panel of the screen **20** may be selected to activate instrument planning. When selected, the icon may switch to the visible icon. The desired implant label may be selected on the right panel of the screen **20**. Using a verified instrument, the desired trajectory may be navigated on the patient images. The foot pedal may be pressed or the confirm trajectory button may be selected to save the desired implant location. Once the planned implant **182** is dropped on the image **160**, the implant planning features may be used to adjust implant location by dragging the implant image **182** on the touch screen **20**. The specific implant size may be selected (e.g., width, length, height, lordosis) on the right panel of the screen **20**. A blue icon may confirm the trajectory with a click to drop the implant **182** on the patient images **160**. A hand symbol may indicate the instrument planning icon with a click to transition to instrument planning mode. An eye symbol may indicate a visible icon to indicate that the user is in the instrument planning mode. The level bubble indicator **184** may indicate the active implant being planned and the spinal level.

Turning to FIGS. **20**F and **20**G, the navigation tab **170** may allow for disc preparation, trialing, and interbody placement. Prior to navigation, the motion lock end effector **22** can be used to attach the access instrument **34** (e.g., retractor or access port) for surgery if desired. Following draping, the user can move the robotic arm **14**, for example, under wrist mode by pressing the bracelet or the foot pedal. The user moves the arm **14** manually to a desired position within reach of the surgical area, close to the surgical site. The sterile motion lock end effector **22** is then attached to the robotic arm **14** over the drape **28**. This locks motion of the robotic arm **14**. The retractor or port **34** may be attached to the articulating arm **24** to rigidly fix its position and orientation for the duration of the procedure, providing an access corridor to the spine. The articulating arm **24** and retractor or ports **34** may not be displayed on the monitor **20**. The articulating arm **24** may be secured to the motion lock end effector **22** by pressing the release button **36** and attaching it. The retractor or port **34** may be attached to the attachment mount **38** of the articulating arm **24**. If desired, the dilator array **114** may be attached to the initial dilator **112** to navigate to the starting position and trajectory of the retractor or port **34**. Once the desired position is established, the articulating arm **24** on the desired retractor or port **34** may be connected to the attachment mount **38**. The locking knob **40** is secured to lock the articulating arm **24**. Once the articulating arm **24** and retractor or port **34** are in the desired position, the surgical procedure may be performed.

In FIG. **20**F, after assembling the desired instruments **50** (e.g., disc preparation instruments and trials) to an array handle **52** and instrument verification is performed, the instrument **50** may be assigned to the given array **56** by clicking the "Array Identifier" button. The correct index position **74** may be identified by clicking the "Array Index Identifier" button. Once the array **56** has been verified, disc preparation and trial instruments **50** may be switched out during the procedure but the new instrument **50** must be re-assigned and the array index position **74** adjusted accordingly in order for the instrument **50** to be correctly displayed for navigation. An anatomical landmark check may be performed to ensure that the instrument **50** is not damaged and the instrument settings are correctly set. Disc preparation and trialing may be performed using the navigated instrument assembly **186** displayed on the screen **20**.

In FIG. **20**G, the interbody implant may be placed. The trial may be assigned to the array handle **52** by clicking the "Array Identifier" button. The correct index position **74** may be assigned by clicking the "Array Index Identifier" button. The trial may be navigated to the desired location. The trial may be inserted into the disc space. This may be repeated for various trials until the desired implant size is determined. The inserter **80** may be selected corresponding to the interbody device being used. Instrument verification may be performed using the verification adapter **130** or the implant. The desired interbody implant is attached to the inserter **80**. The implant size may be selected (e.g., width, length, lordosis) on the right panel of the screen **20**. The interbody implant is navigated to the desired location and the virtual inserter and implant **188** are displayed on the patient images **160**. The implant is inserted into the disc space based on the navigational information displayed, for example, on monitor **20**. For expandable spacers, the corresponding torque-limiting driver may be used to expand the device. The interbody software module may provide for navigation of access, preparation and/or placement of the interbody fusion devices.

Turning now to FIGS. **21**A-**21**H, another embodiment of a navigable dilator instrument or dilator **210** is described in further detail. Navigable dilator **210** may be similar to dilator **110** shown in FIGS. **14**A-**14**G. The navigable dilator **210** may include an initial dilator **212** and a dilator holder or dilator array **214** configured to be tracked by the robotic navigation system **10**. The dilator array **214** may include a unique array pattern, a cavity or attachment window **216**, a release button **218**, and a verification reference feature **220**. Similar to array **114**, array **214** may have one or more posts **222** (e.g., four posts **222**) for attaching tracking markers **18** thereto.

In a minimally invasive spine surgery, sequential dilation may be used to gain access from an incision to a surgical target, typically the intervertebral disc space. Fluoroscopy (x-ray) may be used to target the incision, disc space, and retractor location. Fluoroscopy is also used to ensure that the dilator is inserted along the desired trajectory to access the disc space. The initial dilator is inserted into the incision and traversed through soft tissue while the trajectory is confirmed with multiple x-ray images. The surgical site may be sequentially dilated by placing larger cannulas over the initial dilator. The retractor may be inserted once the site is sufficiently dilated. The retractor provides a working corridor to insert osteotomy, discectomy, and interbody instruments into the disc space. However, the patient, surgeon, and surgical staff may be exposed to potentially harmful radiation due to the amount of fluoroscopy required for this method of dilation. In addition, complications may arise from an inaccurately placed instrument. Finally, this method may be time consuming which reduces surgical efficiency and patient safety.

With the robotic navigation system **10**, the initial dilator **212** may be navigated by the system **10** while greatly reducing or eliminating the need for intraoperative fluoroscopy, increasing accuracy, and/or increasing intraoperative efficiency. The system allows for tracking full rigid body motion of the surgically navigated dilator **210** through surgical robotic navigation technology. With the surgical robotic navigation, the instruments **50**, **80**, **110**, **210** may be

tracked through optical or electromagnetic position sensors **18**, the associated computer-aided design (CAD) model may be displayed relative to anatomical landmarks, and/or the instruments **50**, **80**, **110**, **210** may be guided to planned positions using the robotic system **10**.

Surgical navigation or robotic navigation systems may track the full rigid body motion of an instrument **50**, **80**, **110**, **210** by measuring the position of an array **56**, **82**, **114**, **214** of optical or electromagnetic markers **18** relative to one another. A model may be mapped to these measured marker locations, oriented in 3D space, and displayed relative to anatomical images for the surgeon. One way to ensure the orientation of the tracking array **56**, **82**, **114**, **214** is to rigidly mount the array to the tool. For the dilators **110**, **210**, however, it may not be possible to rigidly and permanently mount the array **114**, **214** to the tool.

Sequential dilation includes using dilators of increasing diameter to be subsequently inserted into the soft tissue. To maintain the target trajectory and prevent tissue damage, sequential dilation may be accomplished by placing each larger dilator concentrically around a previously inserted dilator. The initial dilator **112**, **212** may be placed with the assistance of robotic navigation. The removable tracking array **114**, **214** may be removed. Then, subsequent dilators may be inserted. The array **114**, **214** may be re-attached to track the position of the dilators while placing the retractor or other access instrument **34**. In this way, the removable array **114**, **214** acts as a navigated dilator holder. Through this method, the initial dilator **112**, **212** may be directly navigated and the retractor or other access instrument **34** may be indirectly navigated. Once the desired trajectory and depth are determined through navigation, the retractor or other access instrument **34** can be rigidly fixed in place and the dilators and tracking array **114**, **214** may be removed.

In addition to the dilator and retractor placement, there may be other benefits to a navigated dilator holder or array **114**, **214**. Dilator sizes and styles may be unique to a particular retractor system. A universal navigated dilator holder **114**, **214** which accommodates various sizes and styles of initial dilators **112**, **212** may help to reduce set complexity, improve intraoperative efficiency, and/or improve flexibility for accommodating various surgeon preferences. When coupled to the initial dilator **112**, **212**, the device **114**, **214** may also serve as a navigated probing tool for identifying landmarks, measuring depths, and/or verifying trajectories in the anatomy. The adaptability of the navigated dilator holder **114**, **214** may allow it to be attached to instruments or instrument adapters and used as a reference array for verifying the tracking accuracy of other instruments and instrument arrays.

With reference to FIGS. **21**A-**21**C, one embodiment includes the navigable dilator holder or removable array **214** rigidly attached to the initial dilator **212** with a mechanism capable of quickly attaching to and detaching from the initial dilator **212**. The navigated dilator holder **214** is able to attach to and detach from initial dilator **212**, with or without subsequent larger diameter dilators present. In addition, the array **214** may repeatedly attach to and detach from initial dilators **212** or other verification instruments to ensure positional accuracy of the distal tip of the instrument. The verification reference point **220** may be used to verify other navigated instruments. The initial dilators **212** may be placed with a k-wire attached, if desired. The navigated dilator holder **214** may contain a hole or slot **224** for the k-wire to avoid interference with the inserted k-wire.

As best seen in FIG. **21**C, the rigid body of the array **214** may include a v-block **226** and a depth stop **228** to accurately locate an axisymmetric instrument, such as initial dilator **212**. In this embodiment, the dilator **212** may be rigidly located with respect to the array **214** via a spring-loaded mechanism **230**. The initial dilator **212** may be inserted into the cavity **216** in the rigid body containing the v-block **226**, depth stop **228**, and spring-loaded mechanism **230**. The array **214** is rigidly attached to the dilator **212** with the spring-loaded quick release button **218** for attaching the array **214** and accurately locating the initial dilator **212**. If the spring-loaded mechanism **230** is compressed, such as through the push of the button **218**, the size of the cavity **216** is increased allowing easy insertion and removal of the instrument **212**. When the spring-loaded mechanism **230** is decompressed, such as through releasing force on the push button **218**, the size of the cavity **216** decreases and the inserted dilator **212** is centered in the v-block **226** through a transverse force provided by a force applicator **232** coupled to the spring-loaded mechanism **230**.

In another embodiment shown in FIGS. **21**D-**21**H, the transverse force is provided by a screw-based mechanism **234**. The v-block **226** is screw-driven by a screw **234** or other suitable mechanism for attaching the array **214** and accurately locating the initial dilator **212**. In each embodiment, the variability of cavity size and self-centering nature of the v-block **226** allows for insertion of a variety of dilator sizes and styles. In addition, each embodiment may include the slot **224** for insertion of k-wires with or without the dilators attached. The depth stop **228** also provides repeated insertion depth of the dilator **212** in the attachment mechanism, which enables accurate tracking and prevents interference with larger diameter subsequent dilators. The initial dilator **212** may be tracked through robotic navigation methods, which reduces or eliminates the need for fluoroscopy while dilating the surgical site and placing the retractor or access instrument **34**. The tracked array **214** may be quickly and repeatedly attached to the dilator **212** enabling subsequent dilation without interference with subsequent dilators or anatomy. The tracked array **214** accommodates various initial dilator sizes and styles which may reduce set complexity, improve intraoperative efficiency, and/or improve flexibility for accommodating various surgeon preferences. The tracked array **214** may be used as a reference array for verifying the accuracy of other instruments or instrument arrays.

Turning now to FIGS. **22**A-**22**C, embodiments of instruments **250** with a removable shaft **254** and/or removable tip **258** for are shown. Instrument **250** may be similar to the instruments **50** shown in FIGS. **6**A-**9**F. Although markers **18** are not shown, it will be appreciated that suitable arrays **56** and markers **18** may be included on these instruments **250**, if desired. Often during medical procedures, instruments may undergo stresses that lead to wear and occasionally to damage. Once worn or damaged, tools require replacement, and due to the one-piece or uni-body construction of the tools, replacement carries a high cost and a large amount of space used in the operating room to store cases containing replacement instruments. Accordingly, in some embodiments, the instruments **250** may include removable shafts **254** and/or removable tips **258**. Replaceable tips **258** may be advantageous as less full-size equipment is needed in the operating room with each tool only needing one shaft **254** and/or a supply of separate tips **258**.

The removable shafts **254** and/or removable tips **258** may offer a reduction of size and number of instruments and graphics cases required in the operating room. In addition, operating room efficiency may be improved by the decreasing the number and size of instruments on the back table and

Mayo stand. In addition, the removable shafts **254** and/or removable tips **258** enables replacement of the worn component (e.g., tool tip) rather than the entire instrument which decreases cost of maintenance and repair. As less handle and shaft components are required, the cost of manufacturing each instrument set is also decreased. Also, the modularity may enable low-cost, surgeon-specific instrumentation as simplified custom tool tips may be created to fit a common shaft-handle assembly.

In one embodiment shown in FIG. **22**B, the instrument **250** includes a modular two-piece instrument design. The handle **252** may include a quick-release mechanism **260** that mates to an instrument shaft **254** with an integrated tip **258**. The multi-piece instruments **250** may be found in sizing applications where many incremental sizes are needed in the instrument set (e.g., sizers, shavers, paddle distractors, trials, etc.). The modular set may decrease the cost and size of the instrument set.

Over the course of time, tools may be damaged in surgery or worn out from repetitious uses over multiple cases. When the instrument requires service due to wear or damage, the entire one-piece instrument must be replaced. Even in the case of two-piece instruments, the shaft-tip construct may need to be replaced. In one embodiment shown in FIG. **22**C, the tool tip **258** may be replaced. For example, the instrument **250** may include a handle **252**, a shaft **254** coupled to the handle at connection **262**, and a replaceable tool tip **258** coupled to the shaft **254** at connection **264**. The connection **262** may be a rigid, permanent connection between the shaft **254** and handle **252** or may also be modular.

As shown in FIG. **22**C, the connection **264** may provide for repeatable and durable attachment of the tool tips **258** to the shaft **254** of the instrument **250**. The connection **264** may allow for temporary retention, rotational constraint, and/or axial "pull-out" constraint of the tip **258**. Temporary retention of the tool tip **258** in the instrument shaft **254** prevents the tip **258** from accidently falling out under gravitational forces when the tip **258** is replaced. Rotational constraint preserves the position of the tool tip **258** with respect to the handle **252** under typical torsional loading conditions in a surgical environment. Similarly, axial constraint preserves the axial position of the tool tip **258** and prevents unintentional release of the tool tip **258** under typical axial loading conditions in a surgical environment.

Temporary retention of the tool tip **258** may be accomplished through one or more mechanisms including but not limited to magnetism, friction, and/or clamping force. In one embodiment with a magnetic-ferromagnetic connection **264**, the proximal end of the tool tip **258** contains a magnet that mates to a ferromagnetic feature of a release mechanism on the distal end or interior cavity of the instrument shaft **254**. In another embodiment with a ferromagnetic-magnetic connection **264**, the proximal end of the tool tip **258** may contain a ferromagnetic feature that mates to a magnetic feature of the release mechanism on the distal end or interior cavity of the instrument shaft **254**. In yet another embodiment with a magnetic-magnetic connection **264**, the proximal end of the tool tip **258** may contain a magnet that mates to a magnetic feature of the release mechanism on the distal end or interior cavity of the instrument shaft **254**.

According to another embodiment, the proximal end of the tool tip **258** may contain a tapered male feature that mates to a tapered female feature of a release mechanism on the distal end or interior cavity of the instrument shaft **254**. In yet another embodiment, the proximal end of the tool tip **258** may contain a tapered female feature that mates to a tapered male feature of the release mechanism on the distal end or interior cavity of the instrument shaft **254**. The tapered features may include, but are not limited to, tapered three-dimensional geometries such as conical surfaces, tapered cylinders, and tapered prisms. The function of these male-female pairs of tapered surfaces is to create an interference fit between assembled components such that the components are temporarily fastened via friction but can be disassembled with sufficient axial force.

According to another embodiment, the release mechanism on the distal end or interior cavity of the instrument shaft **254** may contain an O-ring or other compressible flexure that depresses and applies a clamping force when the proximal end of the mating tool tip **258** is assembled. In another embodiment, this compressible flexure may be a linear spring. In other embodiments, the clamping force may be provided by a latch-hook mechanism or ball plunger and detent mechanism.

According to another embodiment, rotational constraint of the tool tip **258** may be accomplished through a variety of mechanisms, including but not limited to, three-dimensional screw drive features or threads. Screw drive features may be used to provide rotational constraint in fasteners, such as screws or bolts, which function in male-female pairs. In one embodiment, the male feature may be located on the proximal end of the tool tip **258** and the female feature may be located in the release mechanism **264** on the distal end or interior cavity of the instrument shaft **254**. In another embodiment, the female feature may be located on the proximal end of the tool tip **258** and the male feature **254** may be located in the release mechanism **264** on the distal end or interior cavity of the instrument shaft **254**. Male-female pairs of screw drive features may include geometries such as square, hexagonal, pentagonal, slotted, hexalobular, spanner, clutch, cross slot, or combinations of these geometries. In yet another embodiment, the rotational constraint may be provided through threaded male-female pairs.

According to another embodiment, axial constraint of the tool tip **258** may be accomplished through one or more mechanisms including but not limited to threaded mechanisms, quarter-turn locking mechanism, half-turn locking mechanism, and hook-latch mechanisms. In each embodiment, the axial constraint may be accomplished by male-female pairs of features where the male feature is located on the proximal end of the tool tip **258** and the female feature is located in the release mechanism **264** on the distal end or interior cavity of the instrument shaft **254** or vice versa. Threaded mechanisms, quarter-turn locking mechanisms, and/or half-turn locking mechanisms may be actuated through torsional force applied in a twisting motion. In contrast, the hook-latch mechanisms may be actuated through transverse loading of a release button on the instrument shaft **254**.

In a traditional operative setting, several cases of large instruments are manufactured, transported, stored, sterilized, and unpacked prior to surgery. In contrast, the instruments **250** may allow a set of smaller tool tips **258** and/or fewer common handle-shaft constructs to be used in place of several, large cases of instruments. One benefit may be the availability of a variety of tool tips **258** in a smaller, cheaper, and more efficient package. The functionality of the traditional tool tips may be preserved while enabling pre-operative or intra-operative replacement. The tool tip **258** geometries may include, but are not limited to, drills, taps, awls, screwdrivers, cannulas, cup curettes, ring curettes, osteotomes, cobbs, elevators, rasps, rakes, paddle distractors, sizers, shavers, scrapers, trials, and implant inserters.

Surgeons sometimes prefer custom instrumentation to meet specific functional, ergonomic, or aesthetic requirements beyond the standard, traditional instrument offering. Medical device companies sometimes cater to these needs by custom manufacturing surgeon-specific instruments, which may be extremely costly and time consuming. By isolating customization to the critical component of the instrument (e.g., the tool tip **258**) rather than the entire instrument, time and/or money may be saved. The custom tool tips **258** may be attached to a common handle-shaft construct. Such tool tips **258** may be co-designed with surgeons to meet preferred specifications and produced with traditional or advanced manufacturing methods. By using advanced manufacturing methods such as 3D printing or CNC machining, custom tool tips **258** may be produced in an automated environment with greater complexity and at a lower cost.

Turning now to FIGS. **23**A-**23**E, embodiments of navigable instruments **270** with quick-connectors **278** are shown. Instruments **270** may be similar to the instruments **50** shown in FIGS. **6**A-**9**F, for example. The navigable instruments **270** may include a handle **272** and array **276** with tracking markers **18**, and an instrument shaft **274** capable of quick release or connection to the handle **272**. The array **276** may be affixed to the handle body **272** with an array post **280**. The array **276** may be fixed in position relative to the handle **272** or may be configured to rotate as described in other embodiments. Although a straight handle **252** is shown, it will be appreciated that a T-style handle or other suitable handle may be used.

In surgical navigation, some tracked tools (e.g., a drill, tap or screwdriver) may be axially symmetrical. For example, a representation of a drill looks the same no matter how the drill bit is rotated. The tracking array **276** for such tools can be mobile in its rotational coordinate about the tool since the rotational position of the tool does not need to be monitored. Therefore, marker arrays **276** for tracking these symmetrical tools may be designed with the array **276** on a sleeve that is free to rotate about the tool. The user can reposition the array **276** about the tool shaft as necessary to keep it facing toward the tracking cameras **30** while using the tool. However, it is sometimes necessary to track a tool that is not symmetrical (e.g., aa curved curette or a delivery device for an interbody spacer). In such cases, the system **10** may track the full rigid body position of the tool so that it can properly update the image of the tool overlaid on anatomy, showing, for example, which direction the curve or cutting surface of the curette faces. In these tools, different features may be used to ensure the tracking array's orientation is fixed relative to the tool in all directions including rotation. In addition, it may be desirable to attach and detach different tools to the tracking array intra-operatively without re-calibration of the tool-array assembly. This may need a rigid connection, which is accurate and repeatable.

According to one embodiment shown in FIGS. **23**A-**23**C, the instrument shaft **274** may be attached to the handle **272** and tracking array **276** assembly with a quick-connector **278**. The quick-connector **278** may include an extension **282** protruding from the proximal end of the tool shaft **274**. The extension **282** is configured to be received in a bore **284** within the distal end of the handle **272**. The tip **286** of the extension **282** may be tapered or otherwise configured to enhance receipt into the bore **284** of the handle **272**. As best seen in FIG. **23**B, the top of the tool shaft **274** may include a radial shoulder **288** with one or more tapered surfaces **290**, and the base of the handle **272** may include one or more corresponding tapered surfaces **292**. In this manner, the shaft **274** may be connected to the handle **272** and attached array **276** by incorporating two opposing tapered surfaces **290**, **292** onto both the tool shaft **274** and the handle **272**, such that the tapered surfaces **290**, **292** make contact with one another, simultaneously constraining three rotational and two translational degrees of freedom of the tool. The last degree of freedom is constrained by the extension **282** of the tool shaft **274** into the bore **284** of the handle **272**.

A button or latch **294** within the handle **272** may allow for quick release and attachment of the shaft **274**. The bottom of the latch **294** may be received in a slot, groove, or recess **298** defined within the extension **282**. The latch **294** positioned within the recess **298** in the extension **282** retains the instrument and controls orientation. When fully inserted, the base of the latch **294** is received within the recess **298** and the instrument **270** is locked. The handle **272** may house a tapered latch **296** for preload of the extension **282**. By incorporating the latch **294** into the handle **272** and tracking array **276** assembly, which may preload the two components together, backlash or "slop" between the tool shaft **274** and handle **272** may be reduced or eliminated. The quick-connector **278** is able to quickly connect and disconnect from the handle **272**, thereby providing for rigid attachment.

As shown in FIG. **23**D, another embodiment of the quick-connector **278** is shown. The quick-connector **278** may include one or more cross-pins **300** configured to be received in one or more slots **302** in the handle **272**. A transition **304** between the radial shoulder **288** and the extension **282** may include a tapered surface, a curved surface, a stepped surface, or any suitable transition. In one embodiment, the transition **304** is a male conical tapered surface **304**, and the base of the handle **272** may include a corresponding female conical tapered surface **308** in communication with the central bore **284**. The pin **300** may extend from the transition area **304** and may be transverse (e.g., generally perpendicular) to the central longitudinal axis of the shaft **274** and extension **282**. The quick-connect interface may include the mating conical tapers **302**, **304** combined with the cross-pin **300** to prevent rotation and provide a rigid connection between the shaft **274** and handle **272**. The same or similar latching mechanism **294** as described for FIGS. **23**A-**23**C may be used to maintain the connection and/or preload the components together.

As shown in FIG. **23**E, another embodiment of the quick connecting mechanism is shown. In this embodiment, the mating interface may include three flat tapered surfaces **308** configured to mate with three corresponding flat tapered surfaces. For example, the flat tapered surfaces may be oriented radially 120° apart from one another. The geometry may constrain the six degrees of freedom of the tool, center it along the tracking array's axis, and allow attachment in one rotational orientation. It will be appreciated that different or additional mating surfaces or features may be selected to rigidly couple the shaft **274** to the handle **272** and array **276** for navigation of the instrument **270** by the system **10**.

Turning to FIGS. **24**A-**24**B, an instrument **310** including handle **312**, shaft **314** with tip **318**, and tracking array **316** is shown in two different instrument positions. In FIG. **24**A, the instrument **310** is shown in a first position and in FIG. **24**B, the instrument **310** is shown in a second position. Although the tip **318** of the instrument **310** is oriented in two different directions, the array **316** is visible to the camera **30** and the system **10** is able to the track the array **316**. The instrument **310** may include any of the instruments described herein or other suitable instruments for surgical navigation.

In surgical navigation, instruments **310** may be tracked through optical or electromagnetic position sensors **18** and an associated computer-aided design (CAD) model is displayed relative to anatomical landmarks. In surgical robotic navigation, the instruments **310** may also be tracked and guided to planned positions using the robotic system **10**. Surgical navigation or robotic navigation systems may track the full rigid body motion of an instrument **310** by measuring the position of the array **316** of optical or electromagnetic markers **18** relative to one another. With optical tracking systems, this may be achieved via a position sensor (e.g., camera **30**) placed within the operating theater such that the tracked tools **310** are within its line-of-sight. A CAD model is mapped to these measured marker locations, oriented in 3D space, and displayed relative to anatomical images for the surgeon. One way to ensure the orientation of the tracking array **316** is known relative to the entire tool **310** is to rigidly mount the array **316** to the tool **310**.

When the implant and instrument are axisymmetric, the array of markers and rigidly fixed instrument can be rotated to orient towards the camera **30**, and the desired orientation of the instrument and implant relative to the anatomy is not compromised. In the case of non-axisymmetric instruments and implant inserters, however, there may be a case in which rotation of the instrument to maintain line-of-sight with the camera **30** causes an un-desirable orientation of the instrument relative to the anatomy. One embodiment is to enable rotation of the array **316** of optical markers **18** about the instrument's axis, so that the instrument **310** may be placed in the desired orientation relative to the anatomy, and the array **316** may be rotated independently toward the camera **30**. In order to allow the CAD model to be mapped accurately to the measured marker locations, the orientation of the instrument relative to the instrument's axis must be known. In one embodiment, an indicator **336** to the user of the rotational position of the array relative to the inserter's axis may be provided, and then corresponding rotation of the displayed CAD model may be shown on screen **20**.

Turning to FIGS. **25**A-**25**C, an embodiment of instrument **310** with a rotatable body **320** is shown. The handle **312** includes rotatable body **320** and array post **322** may couple array **316** to the rotatable body **320**, and thereby provide for rotation of the array **316**. The array **316** and body **320** may be free to rotate about the longitudinal axis A of the instrument. Axis A may include the central longitudinal axis of the handle **312** and/or the central longitudinal axis of the shaft **314**. The array **316** may be rigidly attached to the body **320**, which is capable of rotating on a cylindrical portion of the instrument's handle **312** which is concentric with the handle's axis A. The array **316** may contain one or more markers **18** rigidly fixed in known positions measured by the position sensor. In one embodiment, the array **316** may be able to index in two discrete rotational positions in order to align with the expected instrument orientations and camera locations within the operating theater. In another embodiment, the array **316** may be able to rotate to more than two discrete positions, such as four positions at 90° increments. It is envisioned that the array **316** may be permitted to rotate to any suitable position.

In FIG. **26**A, an embodiment of an inserter instrument **330** with rotatable body **320** is shown. Inserter **330** may be similar to inserters **80** shown in FIGS. **10**C-**13**B. The inserter **330** may include a shaft or sleeve **332** and a tip **334** (e.g., a forked or threaded tip) for retaining an implant. The rotatable body **320** may be free to rotate about the sleeve **332** to provide for rotation of the array **316**. The array **316** and body **320** may be able to rotate about the central longitudinal axis A of the sleeve **332**. The body **320** may include a rotational position indicator **336**. The indicator **336** may provide the user and/or system **10** with information regarding the rotational position of the array **316** relative to the shaft **332** and/or the inserter's axis A.

Turning to FIGS. **26**B and **26**C, one embodiment of rotatable body **320** is shown in greater detail. FIG. **26**B shows a cross-section perspective view, and FIG. **26**C shows a cross-section top view. The rotatable body **320** may be a rigid body that includes array post **322**, and the array **316** may be attached to the free end of the array post **322** with a fastener **338** (e.g., a screw). The rotatable body **320** includes a cavity that houses a translating member **340** including a tapered key **342** at one end of the translating member **340**. The tapered key **342** is configured to mate with one or more recesses or keyseats **344** in the shaft **332** of the inserter **330**. When the array **316** has two index positions as shown in FIG. **26**B, two opposed keyseats **344** may be present. It will be appreciated that any suitable number and orientation of keyseats **344** may be used to achieve the desired indexing of the array **316**. The taper may allow the tapered key **342** to translate as far as necessary to fully seat in one of the keyseats **344** and remove any clearance from the assembly, thereby eliminating any movement between components. A spring **346** may be positioned at the end of the translating member **340** opposite the key **342**. The spring **346** provides force for holding the key **342** in the keyseat **344**, which can be overcome via a user input, such as a push button **348**. When the button **348** is depressed and the spring **346** is compressed by the user, the tapered key **342** translates away from the keyseat **344**. When the spring **346** is compressed, the array **316** is permitted to rotate about the inserter shaft **332** until the key **342** reaches the next tapered keyseat **344**. The button **348** may be released and the key **342** engages with the next keyseat **344**. In the case of two keyseats **344**, the array **316** may be positioned in one of two index positions that are 180° apart. In the case of four keyseats **344**, the array **316** may be positioned in one of four index positions that are 90° apart.

Turning to FIGS. **27**A-**27**C, another embodiment of a rotatable body **320** is shown. In this embodiment, a spring loaded mechanism is used to hold the array component **316** in the desired orientation with respect to the inserter's axis A, but the spring **350** is arranged such that it is concentric with the instrument's axis A and the force provided by the spring **350** is in an axial direction, rather than the transverse direction. One or more mating tapered surfaces **352** may be used to remove any play from the assembly, with their orientation changed to align with the modified direction of the spring force. Two tapered surfaces **352** may be positioned on the bottom end of the rotatable array body **320**. The tapered surfaces **352** may be symmetric about the instrument's mid-plane. When seated on mating tapers **352** on the inserter **330**, the rotatable array component **320** is fully constrained so that the array orientation is fixed. The array **316** may be set in a position 180° rotated about the inserter's axis A by applying an axial force to compress the spring **350** and separate the tapered surfaces **352** on the rotatable body **320** and the inserter body **330**. This frees one rotational degree of freedom to allow the array **316** to be rotated to its second position. A locknut **354** may be employed to prevent inadvertent spring compression (and array movement) when in the desired position, which may potentially result from impaction loads on the inserter **330** during implant insertion. FIG. **27**A shows the locknut **354** in a downward position causing the mating surfaces **352** to engage between the rotatable body **320** and the inserter body

330, thereby locking the array 316 in a given position. FIG. 27B shows the locknut 354 retracted in a raised position causing the mating surfaces 352 to separate, thereby allowing the body 320 and attached array 316 to rotate.

Turning to FIGS. 28A-28D, embodiments of identification of instrument orientation using an inline array 360 is shown. The inline array 360 allows for line of sight visibility between the tracking camera 30 and instrument array 360 in both directions normal to the array plate 362. For marker patterns that are not symmetric about the instrument axis A, the camera 30 and software are able to distinguish the orientation of the instrument tip 364 with respect to the array plate 362.

In one array configuration shown in FIGS. 28A and 28B, reflective markers 18 are placed on posts positioned about the face of the array plate 362. This arrangement allows line of sight visibility between the tracking camera 30 and instrument array 360 in the direction normal to the array plate face in which the posts and markers 18 are located. If the array plate 362 is rigidly attached to an instrument 366 and the instrument 366 is rotated 180 degrees with respect to the tracking camera 30 visibility may be obstructed by the array plate 362. In FIG. 28A, the array 360 is visible to the tracking camera 30 when the array plate normal direction aligns with the camera field of view. In FIG. 28B, visibility may be obstructed by the array plate 362 when the array is rotated 180 degrees about the instrument axis A. For some screw instruments, this array configuration is adequate because the instruments 366 may be axisymmetric about the instrument axis A.

For instruments 366 with non-axisymmetric tip configurations, such as disc prep instruments, the array configuration may be unable to track the tool tip 364 in all instrument orientations. For example, if a cup curette is used to prepare the anterior and posterior endplates the instrument 366 may need to be flipped 180 degrees during use. With the array configuration in FIGS. 28A and 28B, visibility may be be lost when the instrument 366 is rotated 180 degrees due to obstruction by the array plate 362.

In FIGS. 28C and 28D, the array configuration may include markers 18 located on the edge of the array plate 362. Instead of having markers 18 located on the face of the array plate 362 with posts positioned normal to the array plate face, the posts may be positioned parallel to the face of the array plate 362. By having the markers 18 located on the edge of the array play 362 with the posts positioned parallel to the face of the array plate 362, the markers 18 may be visible from both directions normal to the front and back faces of the array plate 362. In FIG. 28C, a symmetrical configuration is shown with the array plate 362 aligned with the body of the instrument 366. In FIG. 28D, an asymmetric configuration is shown with the array plate 362 offset relative to the body of the instrument 366. In both cases, each array 360 is an inline array 360 with markers 18 located on the edge of the array plate 362 with posts positioned parallel to the array plate 362.

For asymmetric array patterns, the array configuration allows the tracking camera 30 and software to distinguish which side of the array plate 362 and instrument 366 is facing the camera 30. Asymmetric array configurations may include a pattern offset from the instrument axis A, as shown in FIG. 28D. It is envisioned that other asymmetric patterns could be used. For example, an asymmetric pattern may include three posts for markers 18 that are the same length and one that is longer or shorter. The fourth, different marker 18 may indicate the orientation of the tool 366 depending on which side of the tool the camera 30 determines the array 362 is located. In this manner, the software may automatically reorient the displayed CAD model when the instrument 366 is flipped 180 degrees during use.

Turning to FIGS. 29A-29G, embodiments of navigable trials 370 are shown. In interbody fusion, an implant is placed in the vertebral disc space to attempt to restore lost disc height. To ensure that the size of the implant accurately restores the height, trials that match the geometry of implants in the set may be placed into the disc space. Fluoroscopy (x-ray) may be used to verify that the trial is in the correct location and determine which implant size to use. However, the patient, surgeon, and surgical staff may be exposed to potentially harmful radiation due to the amount of fluoroscopy required for trialing. In addition, complications may arise from an inaccurately placed instrument and/or the trialing may be time consuming, which reduces surgical efficiency and patient safety. According to one embodiment, surgical robotic navigation technology may be used to navigate the navigable trial instruments 370 while greatly reducing or eliminating the need for intraoperative fluoroscopy, increasing accuracy, and/or increasing intraoperative efficiency.

The navigable trial 370 may include a modular trial 370 with a removable trial head 372 couplable to an inserter shaft 374. Rather than having the head welded to a rigid shaft, the head 372 of the modular trial 370 is detachable from the navigated instrument shaft 374. The one or more heads 372 are configured to accurately represent each matching implant and may be easily attached and detached from the navigated inserter shaft 374. The trial head 372 is configured to match the outside geometry of one or more implants. As best seen in FIGS. 29A and 29B, the trial head 372 includes a connection portion with a first opening 368. The first opening 368 may be aligned along the central longitudinal axis A of the instrument 370. The trial head 372 may include a second opening 376 transverse to the first opening 368. The trial head 372 may also include one or more slots 378. The slot 378 may extend along the length of the trial head 372.

The trial head 372 attaches to a hook 380 on the inserter shaft 374. The hook 380 may be positioned at the distal end of the shaft 374. The hook 380 may include a protrusion, pin, or peg 382 extending transverse to the shaft 374. The peg 382 may be configured to be received within the transverse opening 376 in the trial head 372. The shaft 374 may include a moveable plunger 384 running through the inserter shaft 374. The plunger 384 may be configured to extend into the opening 368 in the trial head 372. When the plunger 384 is positioned within opening 368 in trial head 372, the trial head 372 is locked in place. The trial head 372 is fixed rotationally by the hook 380 and plunger 384, which allows the trial 370 to be manipulated inside the disc space.

The plunger 384 may be manipulated by a trigger 386. The trigger 386 may be positioned on the outside of the inserter shaft 374. In FIG. 29E, the plunger 384 is deployed by pressing the trigger 386 toward the distal end of the shaft 374. In FIG. 29F, the plunger is retracted by pulling the trigger 386 toward the proximal end of the shaft 374. The trial head 372 may not be placed onto the inserter shaft 374 if the plunger 384 is in its exposed position (shown in FIG. 29E). The trial head 372 may not be removed from the inserter shaft 374 until the plunger 384 is retracted (shown in FIG. 29F). The trigger 386 may incorporate a lock 388, which may be actuated in order to move the plunger 384. The lock 388 may include a push button or a spring-loaded turn and pull mechanism, for example.

The back of the trial inserter **374** may include a quick connector **278**, which may correspond to the couplings for the navigated array handles **50**, **270**. The quick connector **278** may be the same or similar to the quick connectors described herein. This allows for the quick connection of any suitable handle that can be used with the navigation system **10**. Navigated modular trials **370** may eliminate the need for a large number of fixed trials. Instead of needing many trial heads with long fixed shafts, a caddy may be included in the set that features all the trial heads **372**. The detachable inserter **374** can quickly swap between each size.

Turning to FIGS. **30**A and **30**B, another embodiment of the navigable trial **370** may include a fixed trial **370**. Navigated fixed trials **370** provide navigation capability to fixed trials. In this embodiment, the distal end of the instrument **370** contains a rigidly attached trial head **372**. The proximal end contains a rigidly attached quick connector **278** that permits attachment to any suitable handle with a navigation array. The navigated fixed trial **370** may be desired to reduce the need for fluoroscopic images during a majority of the trialing process. In addition, navigated fixed trials **370** offer a rigid, traditional, and simple option for trialing.

Turning to FIGS. **31**A and **31**B, embodiments of navigable expandable trials **390** are shown. Navigated expandable trials **390** may eliminate the need for various trial sizes. Instead of needing many trials heads with long fixed shafts, or many modular trial heads, a single expandable trial **390** may be included in the set that encompasses all the trial head sizes. The navigable expandable trial **390** may include an expandable trial head **392** positioned at the end of the instrument shaft **394**.

The expandable trial **390** may include a tracking array containing a combination of fixed markers **18**A and at least one movable marker **18**B. The navigation array may include at least two fixed position markers **18**A which are positioned with a known location relative to the trial holder instrument **390**. The fixed markers **18**A may not be able to move in any orientation relative to the instrument geometry and may be useful in defining where the instrument **390** is in space. At least one moveable marker **18**B may be attached to the array or the instrument itself, which is capable of moving within a pre-determined boundary (e.g., sliding, rotating, etc.) relative to the fixed markers as defined above. As the trial is expanded, the movable marker **18**B may act as an indication of the extent of expansion to the robotic system **10**. Although the movable marker **18**B is depicted with respect to sliding, rotation of the marker **18**B may be useful to provide information about the implant. Any relative change in position between the set of fixed markers **18**A and the movable marker or markers **18**B may be used. The corresponding software correlates the opposition of the movable marker **18**B to a particular position, orientation, or other attribute of the trial (such as height of an expandable interbody spacer or angle of an articulating interbody spacer).

FIGS. **31**A and **31**B shown an example where four fixed markers **18**A are used to define the expandable trial **390** and a fifth moveable marker **18**B is permitted to slide within a pre-determined path to provide feedback on the trial height. FIG. **31**A shows the expandable trial head **392** at its initial height and FIG. **31**B shows the trial head **392** in an expanded state with the moveable marker **18**B translated to a different position. The translation of the marker **18**B may correspond to the height of the trial head **392**. Although only two positions are shown, it will be appreciated that the movement is a continuous function whereby any given expansion height may be correlated to a specific position of the movable marker **18**B.

In one embodiment, the movable marker **18**B slides continuously to provide feedback about an attribute of the trial based on position. It is also contemplated that the movable marker **18**B may have discreet positions that the moveable marker **18**B are positioned into, which may also be able to provide further information about a trial attribute. With discreet positions, the software is configured to determine each discreet configuration of all markers **18**A, **18**B, which correlates to a specific geometry of the implant holder and/or implant in a specific orientation or at a specific height. In addition, any motion of the movable marker **18**B may be used for other variable attributes of the navigated trial **390**. The navigated expandable trial **390** allows for a single trial instrument that may account for multiple sizes of implants.

Turning to FIGS. **32**A and **32**B, embodiments of navigable awl-tip taps **400** are shown. During spine surgical procedures, in which screws are placed within the anatomy of the spine, drilling and tapping are steps within the procedure that may occur prior to placing the screw. In the embodiments, a sharp tip **402** at the end of the tap may assist during tapping of the screw hole. The awl-tip **402** may assist with partial or full drilling of the screw hole. Navigation of the awl-tip tap **400** may help to ensure the sharp tip **402** of the tap **400** does not pierce unwanted areas of the anatomy.

The goal may be to perform the surgical procedure as quickly and accurately as possible. With this, surgeons may prefer to combine steps prior to inserting the implant, if possible. The awl-tip tap **400** may allow the surgeon to combine the drilling and tapping phase, thus eliminating a step and eliminating some time. The taps **400** may be used to add threads to a hole in bone intended for a screw or threaded device. During surgical spinal procedures, the tap **400** may be used after drilling into the bone to add threads, which allow the screw to be placed and anchor inside the screw hole. The sharp tip **402** may assist with anchoring the tap **400** to the bone and/or drilling through the bone if drilling is not fully completed. The awl-tip tap **400** may have a spiral flute **404** (shown in FIG. **32**A) or a straight flute **406** (shown in FIG. **32**B). The spiral flute **404** may assist with pulling the chips of threaded material to the surface, away from the direction of tapping. The spiral flute **404** may help evacuate the bone chips from the hole during use, which may be advantageous if the surgeon is eliminating the drilling step of the procedure. The straight flute **406** may be used for general purpose. The threads may be lengthened up the shaft of the tap **400**, which may help with the removal of the tap **400** while it is being navigated and constrained by the end effector. A taper along the length of the tap **400** may assist the surgeon with gradually easing into thread forming. The awl-tip taps **400** may be navigated in the same manner described for other instruments.

Although the robot and associated systems described herein are generally described with reference to spine applications, it is also contemplated that the robot system is configured for use in other surgical applications, including but not limited to, surgeries in trauma or other orthopedic applications (such as the placement of intramedullary nails, plates, and the like), cranial, neuro, cardiothoracic, vascular, colorectal, oncological, dental, and other surgical operations and procedures.

Although several embodiments of the invention have been disclosed in the foregoing specification, it is understood that many modifications and other embodiments of the invention

will come to mind to which the invention pertains, having the benefit of the teaching presented in the foregoing description and associated drawings. It is thus understood that the invention is not limited to the specific embodiments disclosed hereinabove, and that many modifications and other embodiments are intended to be included within the scope of the appended claims. It is further envisioned that features from one embodiment may be combined or used with the features from a different embodiment described herein. Moreover, although specific terms are employed herein, as well as in the claims which follow, they are used only in a generic and descriptive sense, and not for the purposes of limiting the described invention, nor the claims which follow. The entire disclosure of each patent and publication cited herein is incorporated by reference in its entirety, as if each such patent or publication were individually incorporated by reference herein. Various features and advantages of the invention are set forth in the following claims.

What is claimed is:

1. A robotic system comprising:

a base, including a computer;

a display electronically coupled to the computer;

a robot arm electronically coupled to the computer and movable based on commands processed by the computer;

an end-effector electronically coupled to the robot arm, the end-effector including a quick-connector;

an articulating arm having a first end coupled to the end-effector by the quick-connector and a second end, wherein the articulating arm includes a release button and the articulating arm is configured to be secured to the end-effector by pressing the release button located at the first end and attaching the articulating arm to the end-effector;

an access instrument coupled to the second end of the articulating arm; and

a camera configured to detect one or more tracking markers,

wherein the end-effector is a motion lock end-effector configured to automatically lock a position of the end-effector when attached to robot arm,

wherein when attached to the robot arm, the motion lock end-effector automatically sends a signal to the robotic system to restrict all motion and prevent unintended movement as a safety feature while the access instrument is used in the patient and the operation is performed.

2. The system of claim **1**, wherein the end-effector is a motion lock end-effector configured to prevent motion of the robot arm when attached to the robot arm.

3. The system of claim **1**, wherein the quick-connector includes a male portion which is receivable within a female portion within the first end of the articulating arm.

4. The system of claim **3**, wherein the release button is configured to allow for quick attachment and detachment of the articulating arm to the end-effector.

5. The system of claim **1**, wherein the end-effector connects to the robot arm by clamping over a sterile arm drape.

6. The system of claim **1**, wherein the second end of the articulating arm includes a threaded attachment mount for attachment to the access instrument.

7. The system of claim **1**, wherein the articulating arm includes a plurality of joints that are configured to be locked and unlocked by a locking knob.

8. The system of claim **1**, wherein the access instrument is a retractor.

9. The system of claim **1**, wherein the access instrument is an access port.

10. A robotic navigation system comprising:

a robot comprising:

a base, including a computer;

a display electronically coupled to the computer;

a robot arm electronically coupled to the computer and movable based on commands processed by the computer;

an end-effector electronically coupled to the robot arm, the end-effector including a quick-connector;

an articulating arm having a first end coupled to the end-effector with the quick-connector and a second end, wherein the articulating arm includes a release button and the articulating arm is configured to be secured to the end-effector by pressing the release button located at the first end and attaching the articulating arm to the end-effector;

an access instrument coupled to the second end of the articulating arm; and

a camera configured to detect one or more tracking markers; and

a navigable instrument including an array of tracking markers trackable by the camera, wherein the navigable instrument is configured to access, prepare, and/or place an interbody implant,

wherein the end-effector is a motion lock end-effector configured to automatically lock a position of the end-effector when attached to robot arm,

wherein when attached to the robot arm, the motion lock end-effector automatically sends a signal to the robotic system to restrict all motion and prevent unintended movement as a safety feature while the access instrument is used in the patient and the operation is performed.

11. The system of claim **10**, wherein the navigable instrument is a trial, cup curette, ring curette, cobb, elevator, osteotome, rasp, rake, sizer, shaver, paddle distractor, or scraper.

12. The system of claim **10**, wherein the navigable instrument is an inserter instrument.

13. The system of claim **10**, wherein the navigable instrument is a dilator.

14. The system of claim **10**, wherein the end-effector is a motion lock end-effector configured to prevent motion of the robot arm when attached to the robot arm.

15. The system of claim **10**, wherein the articulating arm includes a plurality of joints that are configured to be locked and unlocked by a locking knob.

16. The system of claim **10**, wherein the access instrument is a retractor.

17. The system of claim **10**, wherein the access instrument is an access port.

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